Electric Contacts – Physical and Chemical Effects

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Abstract: - The article describes degradation of electrical contacts by intermetallic growth and contains the description of voltage-temperature relation with temperature dependent electrical resistivity and thermal conductivity, which are related to the function of electrical contact.

Key-Words: electric contact, stationary contact, intermetallic compounds, electric intensity, surface layer, discharge inception process

1 Introduction
The common feature of all electrical and electronic devices is the passage of current combined with heating. Sliding contacts of heavy-current electrical devices commute currents reaching 10⁶ A. High current densities in sliding contacts deform contact elements, alter the friction coefficient, intensify wear, and damage the rubbing surfaces. This may be the result of single or combined effects of various phenomena. Current induced temperature rise due to generation of the Joule heat in the contact zone is, however, the most common and evident factor that is frequently studies on the temperature behavior in electrical contacts were undertaken and described in the literature. In the case of static contacts, however, a number of processes such as creep, stress relaxation, and fretting, are found to exert a strong effect on their performances. [3] These problems are also important when electric current is used to heat the contact. Temperature in the contact zone is experimentally determined by measuring the potential drop method is convenient to investigate surface-layers response to heating, and to estimate temperature stability of the base material. Or boundary layers, including lubricating films. It can be a useful research tool to model steady and unsteady conditions in the contact spots, which is otherwise difficult to achieve in friction tests. The effectiveness of the method depends strongly upon the possibility of analyzing temperature fields in the vicinity of the contact, which possess sharp gradients both in axial and radial directions when the current passes through even a pure metallic spot. Distortion of the current line arising from heterogeneity of surface films or their breakdown can impede the analysis. Sliding friction is an additional and important source of heat in electrical contact since friction is a typical dissipative process in which mechanical energy is converted into heat. The thermal state of friction contact is frequently a decisive factor when evaluating the performance of a friction unit. Determination of temperature fields generated by friction is an independent area of tribology. It is commonly believed that heat generation during friction results from deformation of material in the real contact spots. In connection with this, some process can be related to the transformation of mechanical energy into heat, namely, plastic deformation, hysteresis dispersion, and viscous flow. The last process is the most typical for hydrodynamic lubrication being in fact a single source of heat.

2 Voltage-Temperature relations with Temperature – Dependent Electrical Resistivity and Thermal Conductivity

Usually, the dependence on temperature of the thermal conductivity and electrical resistivity can be expressed respectively as

\[ \lambda = \lambda_0 (1 - \beta T) \]  
\[ \rho = \rho_0 (1 + \alpha T) \]  

Over a wide temperature range, where the subscript 0 refers to the value at 0°C and \( \beta \) and \( \alpha \) are the temperature coefficients of thermal conductivity and electrical resistivity respectively. Note that the thermal conductivity of metals generally decreases with increasing temperature whereas electrical increases. Using these forms of the temperature dependence of \( \lambda \) and \( \rho \) produces the following V-T relation

\[ V^2 = 8\lambda_0 \rho_0 [(T_0 - T) + (\alpha - \beta)(T^2 - T_0^2)/2 - \alpha \beta (T^3 - T_0^3)/3] \]  

The curves corresponding to aluminum- copper, copper –brass and aluminum brass junctions fall approximately midway between curves 1 and 2, 1 and 3, and 2 and 3 respectively. Note in all cases that the contact temperature deviates significantly from the bulk
temperature only when the voltage drop across the contact exceeds approximately 10mV. The generation of potential drops in excess of 0.1V produces contact temperatures that can easily lead to softening or melting of the contact material. [1]

Fig. 1 Voltage-temperature relationship for copper – copper, aluminum – aluminum, and brass-brass electrical contacts [1]

3 The Widemann – Franz Law [1]

Equation (3) is an accurate depiction of the V-T Relation, valid over the entire temperature range over which the resistivity and thermal conductivity vary linearly with temperature. For engineering purposes, this relation is difficult to handle. Note that all the curves in Fig. 1 associated with the same bulk conductor temperature lie close together. It may be verified that the V-T curves corresponding to many metals also fall very close to the curves. This surprising observation stems in part from the Widemann-Franz law, which states that the variations with temperature of the thermal conductivity and electrical resistivity of metals are such that \( \lambda \) and \( \rho \) are related by the expression

\[
\lambda \rho = LT \tag{4}
\]

Where \( L \) is the Lorenz constant (2, 45x10^{-8}V^2K^{-2}) and \( T \) is the absolute temperature. Equation holds if thermal conduction and electrical resistivity arise from electronic transport in the metals. Although this relation provides a reasonable description of thermal and electrical transport properties in metals over the temperature range generally relevant to ordinary electrical contacts, it is not universally valid. The origin of the Wiedemann-Franz law is discussed in relation to the electrical and thermal conductivity properties of metals. If the relation (4) hold, then immediately yields the rigorously valid V-T relation as

\[
V^2 = 4L(T_m^2 - T_1^2) \tag{5}
\]

which is indeed independent of the materials in the contact. This equation is not as easy to use as expression

\[
(T_m - T_1) = V^2 / 8\lambda \rho \tag{6}
\]

because the supertemperature \((T_m - T_1)\) cannot be evaluated readily from the voltage drop. It is instructive to compare the values of supertemperature calculated form (6) with those evaluated from the more accurate relation (5) for values of \( V \) that are generally considered excessive for electrical contacts. Consider a copper-copper contact with a bulk temperature \( T_1 \) of 20°C. Using the room-temperature values of resistivity and thermal conductivity of copper respectively as 1, 75x10^{-8}Ωm and 380Wm^{-1}°C^{-1} in equation (6), the supertemperature evaluated from equation (6) and that yielded by the more accurate relation (4) a number of values of the voltage drop \( V \) across the contact. Note that the difference is small and insignificant from the engineering viewpoint for voltage drops as large as 0,05V. This explains the popularity of equation (6) for evaluation of supertemperature. Equation (5) may be reduced to the form of equation (6) by mathematical redefinition and rearrangement of terms. Defining \((T_m - T_1)/2\) as the average temperature \( T_{av} \) in the contact, the evaluation of equation (4) at \( T_{avg} \) yields

\[
\lambda_{av} \rho_{av} = L(T_m + T_1) / 2 \tag{7}
\]

It follows that

\[
(T_m^2 - T_1^2) = (T_m - T_1) \times (T_m + T_1) = (T_m - T_1) \times 2\lambda_{av} \rho_{av} / L \tag{8}
\]

Substituting this expression into equation intend the V-T relation o (5) yields

\[
(T_m - T_1) = V^2 / 8\lambda_{avg} \rho_{avg} \tag{9}
\]

And the V-T relation (6) is recovered with the physical parameters \( \lambda \) and \( \rho \) evaluated at the average connector temperature. Because equation (5) is independent of the specific electrical and thermal conductivity properties of the materials in the contact, it applies equally well to monometallic as to bimetallic contacts provided the
Wiedemann – Franz law does not necessarily imply that the maximum contact temperature occurs at the location of the physical interface.

4 Intermetallic compounds

Aluminum to Copper contacts are increasingly being used in a variety of electrical applications. Such joint, made by friction welding, pressure welding, diffusion and roll bonding, flash welding and explosion welding, are characterized by a relatively stable joint interface and negligible intermetallic formation. In service, however, frequent current surges on the network may generate favorable conditions for interdiffusion to occur and thus, nucleation and growth of intermetallics at or near the initial interface. This, in turn, can seriously impair the overall electrical stability and mechanical integrity of bimetallic joint, since intermetallic phases have much higher electrical resistance and lower mechanical strength [1].

It was found that tensile strength, ductility, impact resistance and electrical resistance of flash-welded aluminum to copper joint are practically unaffected by thermal treatment from two years at 149°C to 5min at 371°C. However, more recent investigation of roll-boded, hot-pressed and flash –welded aluminum-to-copper joint show that the e mechanical and electrical properties are significantly affected by the formation and growth of intermetallics at the joint interface. It was shown that, when the total width of intermetallic phases exceeds 2 – 5 μm, the aluminum–to–copper joint rapidly loses its mechanical integrity. The deleterious effect of intermetallic phases is reflected in the greater brittleness of the contact interface and significantly higher resistance. [1]

5 Applications of Theory

The above theory explain lot of effects which was examine on real operate electrical contact assembly. It was aluminum to cooper joint. Same performance characteristic of contact assembly was inferior, firstly resistance was significantly higher and assembly becomes warmer. Resistance was measured with MOM500, it was confirmed increased volt drop. Contact assembly was taken into parts and analyzed. It was possible to see deleterious effect of intermetallic phases. The measurement confirmed theory of intermetallic compound in the aluminum to cooper join. It is many physical effects of two metals in contact and the effect of chemical reactions at the contact interface. There is also theory concentrates on electric arc and the possibility of arc ignition in the fixed contacts.

The electric field intensity in the small air gaps of granulated film in the interface of electric contact influences the movement of ions. This can possibly result in collision ionization and ignition partial discharges or other processes such as tunneling effect, Schottky emission and hot electron emission.

The electric contact was measured with natural oxide film and a contaminant film. System Powerdiagnostik enabled result process and delimitation partial discharges inception.

The variations of the granulated film and the single cells can be a result of a combination of the different processes occurring at the same time. They are a result of dimension attributes, surface phenomena and abnormalities in element structure of small structures, compared to the bulk material.

The cross interactions of the granulated film cause variations in the heterogeneous structure of the surface layers in the electrical contact.

The results obtained from measurements have confirmed that the heterogeneous structure of the surface layers in the electrical contact in the point of connection conduct the current with above theory.
5 Conclusion

This paper has described possible theory of voltage-temperature relation with temperature dependent electrical resistivity and thermal conductivity in the context of intermetallic compounds.

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References: