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Basic Theory of Contact Resistance

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In low energy electrical contact (or electronic contact) systems, the transmission of low power, analog, and digital signals is moderated by the interface between two metallic surfaces. **Contact resistance** quantifies the opposition to electron flow; it is the total ohmic resistance of the contact members in the closed state. The total contact resistance, R_T, of an ideal contact includes contributions from the *bulk resistance* of the contact materials (R_B), *constriction resistance* at the interface (R_C), and *film tunnel resistance* (R_{ft}):

$$R_T = R_B + R_C + R_{ft}$$

Bulk resistance is a simple calculation of the ohmic resistance of the metal through which current is flowing. Resistance of the contact member is often expressed as a product of the material resistivity, ρ (Ω-m) with the ratio of length to cross-sectional area, l / A (m^{-1}). Bulk resistance increases with temperature for normal metals. The effect of temperature rise may be calculated using the temperature coefficient of resistance (TCR) for each material.

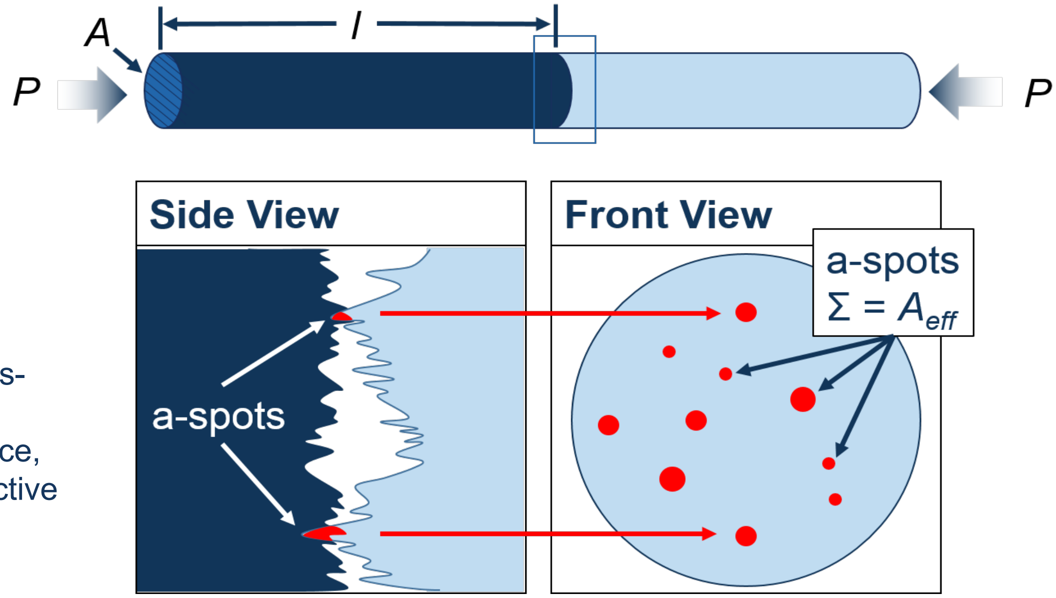

Figure 1: *Schematics including contact dimensions discussed in the text (top) and example of a-spot formation leading to constriction resistance in metal-to-metal contact (bottom)*

Constriction resistance arises from an effective interfacial contact area that is significantly less than the cross section of the conductors. All material surfaces have roughness at the micro- or nanoscale, and so two metals are in contact only where microscopic peaks, or asperites, touch on opposing surfaces. These are called "a-spots." The constriction resistance, R_C, decreases with increasing effective contact area, A_{eff} as $R_C \propto (A_{eff})^{-1/2}$.

Increasing the force applied across the metal-to-metal interface serves to increase the number and size of these contact areas, as does lowering the strength and elastic modulus of the contact materials. Progressively higher forces, P, have diminishing returns on reducing the magnitude of constriction resistance, $R_C \propto P^{-n}$, where n is between ~1/3 and 1.

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Film tunnel resistance occurs because of metal surfaces' natural tendency to collect and/or react with constituents from their environments. Noble metals tend to collect hydrocarbons and other airborne species over time. Non-noble metals (e.g. copper, iron, nickel, etc.) usually react with gasses in the laboratory or industrial atmosphere to form oxides, sulfides, etc. When thin films interpose between metal surfaces at low loads and voltages, electrons can be ballistically transported through the film giving rise to electron tunneling and an associated resistance. In practical contact systems that operate over ~30mV potential and a few grams' load, thin films are sufficiently disrupted that R_{ft} approaches zero.

In addition to the above consideration given to an "ideal contact," real-world applications introduce third bodies in the form of dust, debris, wear products, lubricants, and more. Some or all these factors can interpose in the contact system and act as "series resistors," leading to higher actual contact resistance. Contacts operating below ~12V and ~100mA are not "cleaned" by the generation of a plasma arc like their high-energy counterparts. Thus, low energy contact performance will be influenced by all wear, contaminants, resistive tarnish films, etc. imposed on the contact in service. On non-noble metals, thick, insulating films can gradually develop. The use of noble metal alloys can greatly extend the useful life of low energy electrical contacts by ensuring that metallic surfaces in the contact system remain clean and conductive.

Further Reading

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