IV. MISCELLANEOUS TOPICS

4.1 MULTIPLE CONTACT POINTS. Multiple points of contact acting in electrical parallel are often recommended when reliability is a major requirement of the contact system. The term *reliability* is more applicable to make-and-break systems whereas in liding contact devices the adding of redundant contact points results in a reduction of electrical noise (variation in contact resistance). In either case practical experience has proved that an improvement exits, although not to the full extent forecast by simple probability theory.

The basic reasoning behind the use of multiple contacts is to take advantage of the fact that if there is a dust particle or insulating film under one of several contact members at a certain instant, there is a good probability that at the same instant, one or more of the other members is conducting properly.

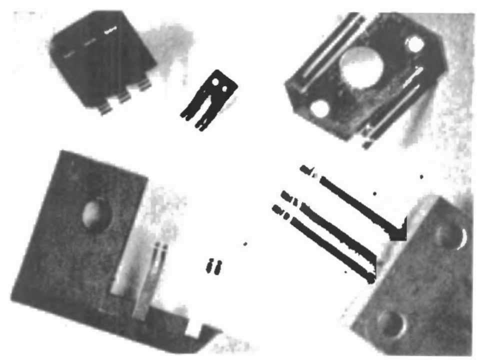

Fig. 4-1. Examples of wipers with multiple points of contact.

Considering the make-and-break contact system first, let us assume that a single pair of contacts repeatedly brought together with a force (**F**) had been tested and found to have a probability of failure (**P**) of .001; that is, it will exhibit abnormally high contact resistance once out of every 1000 operations, on the average. When the number of contacts is increased to (n), each acting at the original force **F** and all being completely independent of one another, the probability that all will fail at the same instant is then P^n.

For the case taken, the failure rate for four contacts would be $(.001)^4$ or 10^{-12}, a failure rate of one in every 10^6 million operations! Possible? Not really, in practical applications, as will be shown.

There are three principal reasons why failure rates of P^n are not realized in practice. Each contact member will seldom be operated at the total original force (**F**) of the single contact. More likely it will be at a force of $\frac{F}{n}$. (Notable exceptions are where single contact force (**F**) was limited only by surface fatigue, brinelling or wear effects, i.e., surplus force was available but not used.)

Also, investigators have found that when a failure of one member occurs, it tends to persist for some period of time before "clearing" or returning to acceptable operation. Thus, they are not single failures randomly distributed a necessary to apply the probability theory that yields $\mathbf{P}^n$.

Thirdly, it is impossible to achieve complete independence of multiple contact . They are physically and electrically interconnected in some way which reduces the idealized performance.

Regarding the force aspect, we know that if it were high enough, even with a single contact point, the reliability is infinite (probability of failure is zero) as regards the contact resistance. Conversely, when the force ap-proaches zero, the probability of failure is 1 (100% failures).

As mentioned, failures from dust particles have a tendency to persist. The work cited was done using dust particles as the principal contaminant but we have seen the same tendency when films are the cause of the high resistance. A contact which develops high contact resistance tends to remain at the high value for more than one operation, its duration dependent on contact force, voltage available to electrically puncture the film, the materials used and the amount of wipe that is present.

The lack of complete independence of each member of a multiple-contact can come from both mechanical and electrical effects. Physically, they are all connected to ome common holding member in the form of a mounting blade, plastic support. Frequently, in the case of multiple wire contacts, the wires touch each other along their full length due to tooling and manufacturing expense of accurate separation. All points normally make contact against the same contiguous surface or at least surfaces which are not far apart dimensionally. These similar closely-spaced surfaces would all have the same average tendency to form and retain films, for example friction polymer, as well as wear debris.

Electrically, the interdependence of redundant contact points in parallel is caused by two possible factors. Assuming the presence of some minor surface films on all surfaces of paralleled contacts simultaneously, and further assuming that the source voltage is sufficient to electrically puncture some films, the film on one contact may be punctured while the others remain intact. Surface films are known to vary widely in thickness even when thickness is checked on two spots just a few mils apart ; therefore, they would need different values of voltage to be punctured. Just as soon as the first puncture takes place, the voltage impressed across the balance drops from the source voltage value to a new value determined by the **IR** drop across the "good" contact. Having had its film punctured, the good contact is the most likely to conduct first on succeeding operations. Simply stated, a film-free contact is prone to remain that way—a filmed one tends to remain filmed when voltage alone is considered as the film-destroying mechanism. This is sometimes called "contact loafing."

A similar electromechanical reason for loafing is when one contact physically makes contact before the other so that the remaining contacts seldom are impressed with full open circuit voltage to help in puncturing their films. This sort of misalignment alway exists to some degree as it is impossible to produce contact assemblies with the members perfectly aligned on a microscopic scale.

Returning now to the influence of force on reliability, to satisfy the conditions that at F = 0, P = l and at F = high, P = 0, Holm[18] proposes the formulas

$$P(F) = \exp\left[-\left(\frac{F}{F_o}\right)^{\epsilon}\right] \qquad \text{Eq. 4.1}$$

and

$$P\left(\frac{F}{2}\right) = \exp\left[-\left(\frac{F}{F_o}\right)^{\epsilon} 2^{(1-\epsilon)}\right] \qquad \text{Eq. 4.2}$$

for twin contacts where the constants Fo = .45 and ε = .6 are determined from empirical data. These formulas were extended by Ellis[11] to cover the case of n redundant contacts acting with a force of $\frac{F}{n}$.

$$P\left(\frac{F}{n}\right) = \exp\left[-\left(\frac{F}{F_o}\right)^{\epsilon} n^{(1-\epsilon)}\right] \qquad \text{Eq. 4.3}$$

The values for F_o and ε observed as 0.45 grams and 0.6 respectively were for noble metals. We feel that these are reasonable values for the purpose of obtaining an approximation of the effect of multiple contacts. A precaution should be added in that forces per individual contact should not be below one gram for the high noble-content alloys as typically recommended by Ney for microcontact devices.

A dramatic example of the benefits of multiple contacts in a make-and-break situation has been shown in a case where failures were reduced from an average of 2.7 failures/10^6 operations to zero failures in tests lasting 13.8 million operations. It was accomplished with the use of Paliney 7 wires which provided four points of contact.

The subject will now be extended to include contact systems which operate in a sliding mode, for example, miniature slip rings and brushes, or rotary switching discs and their brushes.

Assume that a sliding contact system with a single wiper (brush) having a force (**F**) applied has been repeatedly tested and found to have inacceptably high contact resistance (during sliding) for 1% of a given distance of sliding. The probability (**P**) of these high resistance spikes (normally measured as voltage or noise spikes) is then $\mathbf{P}_1$ = .01 for the single contact system. When the number of wipers is increased to (n), each acting at the original force and all being completely independent (except for being electrically in parallel), the probability that all will exhibit high resistance at the same time is P^n. For the case taken of $\mathbf{P}_{(1)}$ = .01, the probability of high resistance with, say four wipers, would be $\mathbf{P}^4_{(1)} = (.01)^4 = 10^{-8}$ or .000001 percent, a phenomenal improvement. While this simplified statistical treatment shows the vast possibilities for improvement through the use of multiple points of contact, in many practical cases circumstances prevent such a large improvement, as will be shown.

The presence of sliding is a distinct advantage in pushing dust particles aside and aids in the mechanical fracture of films. Thus high resistance from dust particles does not have the tendency to persist, except when such particles are imbedded in one of the metal members. In this respect then, multiple points of contact are potentially even *more* valuable in sliding systems than in the make and break systems. In fact, practically all recently designed miniature slip ring assemblies use redundant contacts.

In many sliding systems, the frictional torque must be limited. This would prevent the use of a number (n) of contacts each operating at the original force (**F**) of the hypothetical single contact. More likely they will each be at a force of **F**/n as torque varies directly with the total force applied. Sharing of the force in this manner tends to reduce somewhat the benefits as calculated by the statistical method already mentioned.

Mechanically, there is not complete independence of each member of a multiple-point brush assembly. Physically, they are all connected to some common holding member in the form of a mounting blade or plastic support. Frequently, in the case of multiple wire contacts, the wires touch each other along their length. In the event that electrical noise is initiated by vibration or contact bounce, the mechanical interaction can lower the calculated benefits.

Returning now to the influence of force on the probability of high dynamic contact resistance, the formula used to assess the effect of using a force of **F**/n for each of several contacts is

$$P\left(\frac{F}{n}\right) = \exp\left[-\left(\frac{F}{F_o}\right)^{\epsilon} n^{(1-\epsilon)}\right] \qquad \text{Eq. 4.4}$$

where the best known values of F_0 and ε are 0.45 grams and 0.6 respectively for noble metals. A precaution i necessary in that force per individual contact point should not be below one gram for the high noble-content alloys as typically recommended by Ney for signal level sliding contact devices.

An example of multiple brush benefit is shown in Figs. 4-2 and 4-3, where the noise voltage of a slip ring assembly was measured. The photograph in Fig. 4-2 was taken while twin wire brush contacts were carrying the signal in and out of a rotating ring. Then the redundant members were carefully lifted and the photograph in Fig. 4-3 was taken . Whereas the noise with bifurcation is approximately one millivolt, when the bifurcation is removed noise peaks as high as 11 millivolts can be seen.

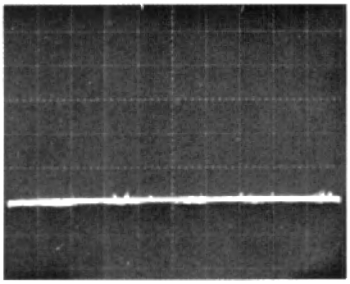

Fig. 4-2. Slip ring noise with bifurcated contacts. Vertical 5 mv/div.; horizontal 2 milliseconds/div.

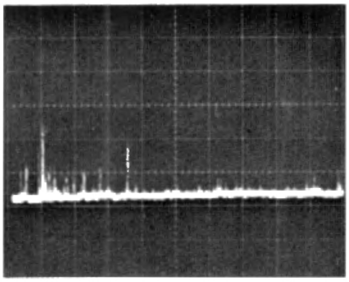

Fig. 4-3. Slip ring noise with single contacts. Vertical 5 mv/div.; horizontal 2 milliseconds/div.