**3.4 MAKE-AND-BREAK APPLICATIONS.** Make-and-break contacts are those whose function is to establish, carry and interrupt current repeatedly, in the absence of gross sliding. Ideally, the resistance between the mating contacts would be insignificantly low when they are closed and infinitely high when they are parted. The number of factors that influence contact performance is very large and their interaction is too complex to permit any simple rules for overall design and material selection. Factors such as current, voltage, contact force and shape, ambient conditions and permissible cost all affect the material selection and the design of the device. Based on the previously covered theory and material properties, as well as practical field experience, some guidance toward sound design can be provided.

As has been the practice throughout this text, the emphasis will be on relatively low energy applications where gross arcing is not a consideration. However, some arcing situations will be covered, to the extent that they apply to noble alloy and a few other commonly used materials.

**3.4.1 Contact Shape.** Mating members in make-and-break systems can be made in round to round, round to flat, cone to flat, crossed rod and flat to flat configurations.

The round to round mating requires careful side and center alignment, the lack of which produces uncontrolled contact force and wipe. For these reasons the round to round is seldom recommended.

Round to flat configurations provide easy alignment and predictable contact force and wipe and are therefore the most often r ecommended when headed contact rivets are employed. If there is a need to concentrate the force, the cone to flat can be used as a modification of the round to flat although this combination is less capable of conducting heat away from the contact interface.

Crossed rod shapes where the radii of the rods are frequently of differing diameters provide ease of alignment, predictable contact force and wipe and are therefore another preferred configuration. One member can have a relatively large radius such as shown in Fig. 3-29 (e) or the weldable ribbon in (f) with the mating member being one or more strands of a smaller diameter wire. Thi scheme is often used when the smaller wire is a self-contained cantilever arm and contact.

A flat to flat mating is seldom recommended. Whereas the intention may be to have them seat throughout their entire flat surfaces, this can never be achieved on a controlled basis. Individual insulation particles are also likely to prevent reliable conduction.

For miniaturized units or at times to conserve noble metal, the preferred shapes already mentioned are produced by dimpling or deep drawing strip material or by wire formed shapes, which provide the surface configuration desired.

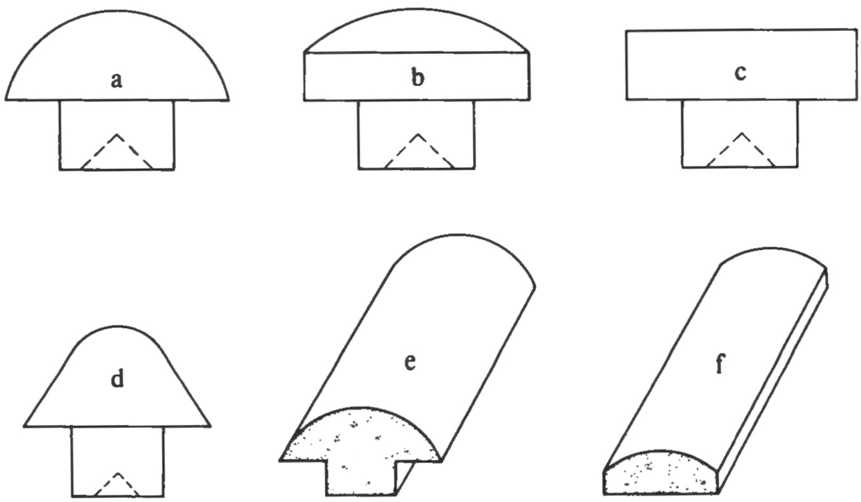


**Fig. 3-29.** (a) Round head contact rivet, (b) fillister head contact rivet, (c) flat head contact rivet, (d) conical head contact rivet with radius, (e) rolled contact shape for staking or soldering, (f) rolled contact shape for welding or brazing.

**3.4.2 Contact Wipe.** Make-and-break contact usually have some degree of wiping present, if not by design, then by inherent flexing of the support members during the making and breaking action. Wiping action is most beneficial in cleaning the surface of minor films and in brushing aside particulate contamination. It also tends to smooth out transferred material and lessen any tendency for the interlocking of asperities and contact sticking. Since wiping always causes some frictional wear, it should not be overdone. A rather small amount of wipe, ordinarily less than .001 inch, is indicated where the metal pair used is not particularly wear resitant. Wear resistant combinations, for example Neyoro G vs Paliney® 7, can tolerate a much greater degree of wipe. The optimum wiping scheme would be one in which the movable contact wipes beyond the point where it finally come to rest, thereby avoiding debris that has been pushed aside.

**3.4.3 Contact Force.** We have already seen (Sec. 1.5 and 1.6) how the amount of force influences the constriction resistance between contacts and the methods for calculating this resistance. For practical purposes, any lowering of the constriction resistance ($R_c$) due to wiping action is ignored and in addition a safety factor of at least 2 is applied to the calculated $R_c$. A force of one gram is the very minimum that can be used even with noble metals, with forces of five grams and above being much more desirable. The semi-noble material silver and its alloys are seldom useful at forces below 30 grams whereas refractory metals such as tungsten and molybdenum cannot be used with forces less than 100 grams.

At times the force available to *break* the contacts needs to be assessed. As a matter of interest, with chemically clean gold the break force is as high as one-half the contact force even when there is no voltage or current present. In the absence of arcing and with more normal ambient conditions, the break force required is a very small fraction of the make force, as the elastic stresses that are stored in the deformed asperities helps the contacts to part. If the contacts close while an arc exists, substantial break forces may be required to fracture large welds ; however, this situation is corrected by selecting materials that have little tendency toward welding and by eliminating bounce.

**3.4.4 Other Mechanical Factors.** As a moving contact mates with a stationary one, there is always some tendency to *bounce* due to the impact With resistive loads and in the absence of arcing, contact bounce does not shorten the life of the contacts although it may be undesirable when the associated circuitry would sense these added openings and closures. When an arc is present, even of short duration, bounce should be minimized, since the contacts will reclose on molten metal and develop macrowelds and possible sticking. Also the number of real operations does not coincide with the number of actuations, but rather is the sum of the number of actuations and number of bounce. Bounce is minimized by lowering the mass of the moving contact, reducing the speed of closure and by dissipating the impact energy through the use of friction.

If the duration of an arc is determined primarily by the instantaneous distance between member (rather than by the discharge time of reactive circuitry) a fast make and break is advantageous. Many "snap action" switches make good use of this principle to extend contact life, preserving a delicate balance regarding contact bounce.

The distance between contacts in the fully open position is termed contact *gap*. Its minimum value is determined by the amount and shape of bridge transfer in non-arcing circuits and by the effectiveness of wiping action in smoothing out bridge transfer asperities. In low energy a-c circuits, the gap can be very small (.002-.003 inch) when desired. It can also be very small for dc if the available circuit voltages always stay below the melting voltage of the contacts.

**3.4.5 Electrical Factors.** Perhaps the most simple application for a make-and-break contact system would be one in which the circuit current and voltage could be selected at any convenient values. Admittedly, this seldom happen but it will be instructional in helping us to apply some basic principles. The voltage and current levels selected for this hypothetical case based on dc, would meet the following requirements:

a) Voltage of the circuit should be high enough to electrically puncture any minor films with ease.
b) Voltage of the circuit should be low enough (including inductive spikes) to prevent any arc from forming.
c) Current should be low enough to prevent arcing and to minimize bridge transfer.

To satisfy the requirements placed on the voltage, we recall that a noble alloy will not sustain an arc if the instantaneous voltage stays below about 10- 12 volts. Some reduction from this value is needed to allow for inductive kicks from wiring inductance. The best compromise in this case would be to select a d-c voltage of 6 to 8 volts. To further insure that arcs will not exist, even when the surfaces are actuated by carbonaceous material, a current below 20 m.a. would serve, say about 10-15 m.a. At this current level and with a little wiping action, bridge transfer would not be an important factor.

Most often the voltage and current levels are imposed on the designer who must assess their influence. From the theory we can expect that the open circuit voltage can be used to classify the modes of operation as follows:

<u>Voltage less than 30 m.v.</u>—There will be complete absence of arcing, melting, bridge transfer, softening and electrical film breakdown. (The inability of this voltage to puncture films is used to advantage in testing assemblies for cleanline and the ability to operate in the microvolt range, where the use of microvolt sources for testing would impose instrumentation difficulties.)

<u>Voltage greater than 30 m.v., but less than softening voltage</u>—There will be complete absence of arcing, melting, bridge transfer or softening, but films that are thin enough will be electrically punctured.

Voltage greater than softening voltage but less than melting voltage—There will be no arcing or bridge transfer. Softening will tend to increase the real area of contact and assist in film fracture. Films that are thin enough will be electrically punctured.

Voltage greater than melting voltage but less than arc sustaining voltage—No sustained arc will prevail but melting will result in bridge transfer. Local high temperature in the molten bridge formed on the break will accelerate oxidation. When film are thin enough to be electrically punctured, molten metal will fill the puncture and solidify.

Voltage greater than the arc sustaining voltage—Depending on the current, some form of arcing will occur. Oxidation will be accelerated by the high temperature accompanying the arc. Arc erosion will be present.

**3.4.6 Alloy Selection.** Were it not for limitations on the space that a contact assembly can occupy and on the mechanical energy that can be provided to make and break the contacts, there would be little need for noble contact materials. We would simply use low cost base metals, pounds of force to mechanically rupture the surface films and have no worry about contact resistance, sticking or other contact problems. Mechanical wear would be the only life-limiting factor. Obviously, such freedom is never given the designer, and his early considerations limit the actuation energy (i.e., contact force) and size. Immediately his attention has to be given to balancing his needs for low contact resistance against the available force, with considerations of the complex inter-relations of reliability, ambient conditions, surface films and electrical load .

**3.4.6.1** In *non-arcing situations* where a high degree of reliability is demanded, the choice of contact materials is restricted to the noble and semi-noble metals and their alloys.

To give some semblance of order to the election process, the first step should be to determine the general class of alloy that is permitted, based on available force and known ambient atmospheric conditions. For example, if the atmosphere will contain sulfur compounds, if the total available force is less than 30 grams, or if long tarnish free shelf life is needed, silver and its alloys are eliminated and the choice lies in the noble family. Further, if the atmosphere is known to contain high organics the gold family of alloys is indicated for at least one member of the contact pair.

Within the family of alloys already selected, the next step in material selection is to calculate some approximate constriction resistance ($\mathbf{R}_c$) values using the total available force as ($\mathbf{P}$) with Brinell hardness ($\mathbf{H}_B$) of the softer alloy and resistivity ($\rho$) values from catalog or handbook information. The equation used is

$$R_c = 1.4 \times 10^2 (\rho_1 + \rho_2)(H_B/P)^{1/2} \qquad \text{Eq. 3.36}$$

where $\mathbf{R}_c$ is in ohms, $\rho_1$ and $\rho_2$ are in ohm-cm and **P** is in grams. It is a good practice to start with the high hardness, high strength alloys (which will usually e those with high resistivity). Then if the calculated $\mathbf{R}_c$ is adequately low compared with resistance requirements, this portion of the task can be set aside and work on other aspects can begin. Should the resistance first calculated from Equation 3.36 be higher than permitted by any large factor, a second calculation could be made, based on pure gold ($H_B \cong 50$, $\rho = 2.3 \times 10^{-6}$ Ωcm) to see if there is any possibility of using noble metals or if relief from some of the design criteria is indicated. Calculations on pure gold are used because it has both low resistivity and hardness.

The calculations of constriction resistances from Equation 3.36 assume rather clean surfaces and are a good guide for newly assembled, clean units. During operation it is certain that some films and debris will raise this value above that calculated. A factor of two should be allowed for very high nobility systems, ranging to a factor of five for lesser nobility or difficult operating conditions which can only be judged empirically from previous designs and experience.

D-c contacts which operate at voltages above a material's melting voltage but at energy levels where arcing is insignificant, are subject to bridge transfer, i.e., if both contact members are of the same material, the cathode tends to build up a spire and a corresponding crater appears in the anode. There are indications that if the anode can be made of a lower resistance, higher melting material, than the cathode, this type of transfer can be reduced.

Discussion in this portion has been principally centered on d-c operation. When a-c energy is being switched, the situation is simpler, in that bridge transfer is not a factor. The transfer continually changes direction and balances out over a short period of time.

At this point in the selection process the choice of materials has been bracketed and the designer will know if the permissible alloys are capable of being used as self-contained cantilever beams and contacts or if separate means of carrying the contacts must be provided. The final selection will involve consideration of such things as elevated temperature relaxation, fatigue, use of multiple contact points, current carrying ability, assembly costs and material costs. Information on all except the latter two can be found by referring to the index for the applicable section of this text.

When the selection and design are completed, performance and life tests under actual condition are mandatory because of the gross interplay among electrical, mechanical and environmental factors. Invariably some improvement can be made after these test results are known.
A few examples of actual applications will serve to illustrate the material combinations frequently used.

Electromechanical Chopper—Paliney® 7 age hardened vs Paliney M annealed. This apparatus makes and breaks at up to 400 times per second in a low organic atmosphere, switching in the millivolt range, 0-2 ma dc for a minimum of 2000 hours life.

Miniaturized Chopper—Neyoro® 69 work hardened vs Neyoro G age hardened. This apparatus makes and breaks at 60 or 400 times per second in an extremely low organic atmosphere, switching in the millivolt range, 0-2 ma dc for 5000 hours life.

Coin Telephone Totalizer—Paliney 7 stress relieved vs Neyoro 69 work hardened. Operation under a wide range of hostile conditions (phone booth) is a requirement. Ten grams of force is divided among four electrically parallel points of contact. Contacts make and break up to 48 volts, with up to 38 ma dc on the break cycle. Life of $2 \times 10^6$ operations is required. (Tests were to $13 \times 10^6$ operations with no malfunctions.)

Punch-Card Sensor Switches—Paliney 7 age hardened vs Neyoro G age hardened. The switches operate for a minimum of 100 X $10^6$ actuation at high speed, switching 5 volts at 2 ma dc, or 14 volts, 3 ma dc.

**3.4.6.2 Arcing Contacts.** Contacts which are required to withstand a substantial amount of arcing are made from special classes of materials, the detailed discussion of which is beyond the scope of this presentation. In general, however, they include materials of the platinum and palladium variety; tungsten and molybdenum, often sintered with silver; and silver which contains cadmium or cadmium oxide. Except for the materials that are high in platinum or palladium, the cited materials require high contact forces. For instance, tungsten and molybdenum are not used at forces less than 100 grams; high silver alloys at not less than 30 grams; silver cadmium oxide at not less than 50 grams.

The possibilities of selecting one material for the anode and another for the cathode can be illustrated by an actual case history in which the available force (25 gram ) was too low to permit tungsten for both members. The desired life was 500 million operations at 60 operations per second, 120 volts, 60 ma dc, electrical load 1.5 henry in series with 2000 ohms resistance. Arc suppression was provided across the contacts and consisted of a 1000 ohm resistor in series with 0.25 $\mu$fd capacitor. Paliney® 7 was tried for both electrodes but the anode erosion limited life to about half of that desired. When Paliney 7 (age hardened) was used as the cathode and tungsten as the anode the life was well in excess of 500 million operations.

Subminiature relays, even though they must withstand considerable arcing, represent a further important use of noble metal alloys. The so-called **TO-5** relay serves as a good example. Paliney 7 alloy, age hardened, is used for all contact members, but in this case the Paliney 7 is overplated with thin gold. The Paliney 7 provides the high strength needed for miniaturization and the ability to operate at high temperature, while the gold aids for the required low energy switching. When the relay is used in arcing situations (28**V**, I amp dc), the gold also assists by providing high thermal conductivity to disperse heat from the contact area.

One further matter that should be covered for arcing situations is the relative ease of interrupting ac as compared to dc. The arc which forms as a result of the rupture of a molten or boiling metal bridge is extinguished when the instantaneous voltage across the contacts approaches the minimum arc sustaining voltage. In cases where the peak voltage being interrupted is less than about 300 volts, the arc will usually not restrike, so that we have a built-in arc suppressor. An additional helpful factor in a-c circuitry is that any electrical erosion is equally shared between the two contact members. As a rule of thumb, switching of 120 volts ac is considered to be equivalent to 28 volts dc where equal currents are involved.