EMI gasket design theory and practice is a specific application of the principles and procedures that apply to the design of any gasketed joint. Therefore, a very generalized gasket design theory is presented first as the basis for the specific EMI gasket design procedures. The EMI gasket design theory and procedures follow and are presented as a specific application of general gasket design.

GASKET DESIGN–WHAT GASKETS DO

All gaskets whether they seal EMI, high pressure fluid, make a container dunk proof or simply keep forced ventilating air from escaping at a door-to-cabinet joint, do so by conforming to the unavoidable irregularities of the mating surfaces of a joint. Some examples are:

–The joint between a garden hose and water faucet.
–Housing for an emergency radio to be dropped into the sea.
–Joint between the cover and enclosure for a radar pulse modulator.

In each example the joint has two relatively rigid mating surfaces, and neither surface will be perfectly flat. When they are mated without a gasket, even very high closing forces will not cause the two surfaces to comply completely with each other, and the resultant gaps will allow leaks. A gasket resilient enough to comply to both surfaces under reasonable force will eliminate these leaks. The garden hose example makes this point very well; just try to prevent a leak by force alone without a gasket, but with a gasket in the hose fitting compressing against the faucet, even hand torque results in a watertight joint. To try to get the same watertightness by accurate machining of both surfaces would be prohibitively expensive. In most cases, the least expensive way to obtain a tight joint (watertight, oil-tight, or EMI tight) is to make the mating surfaces to normal tolerances on flatness, rigidity, and tolerance build-up and add a gasket to compensate for the resulting misfits between the two surfaces.

GASKET DESIGN THEORY

The degree of misfit needs to be defined so that design procedures can be clearly outlined. This misfit is commonly called "joint unevenness" and is designated as H and is defined in Figure 1. It is the maximum separation between the two surfaces when they are just touching. If the surfaces are not rigid, then the joint unevenness would also include any additional separation between the two surfaces due to the distortion of the joint when pressure is applied.

Figure 2 shows the same joint with a gasket installed. The dashed lines indicate the height of the gasket, H_g, before it was compressed. The minimum compressed gasket height, H_{min}, occurs at the point where the surfaces would touch without a gasket. Maximum compressed gasket height, H_{max}, is at the point of maximum joint unevenness. Note that the joint unevenness of the mating surfaces is equal to $H_{max}-H_{min}$. This concept must be kept in mind in all gasket design.

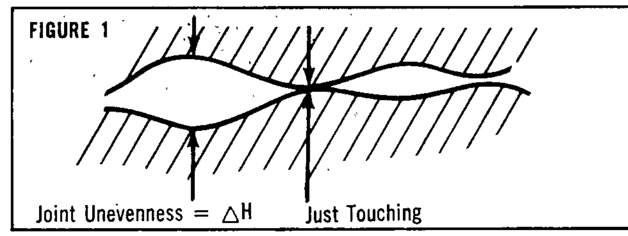
REQUIRED COMPRESSION PRESSURE

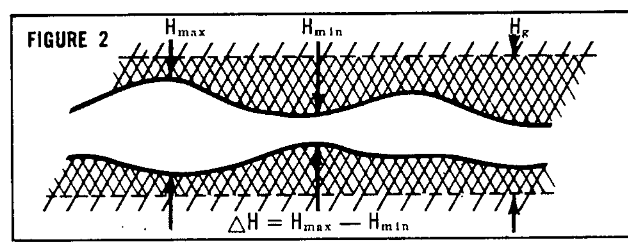
Three factors determine the required compression pressure on a gasket; its resiliency, the minimum pressure required for a seal, and the total joint unevenness.

Resiliency–This is the amount a gasket compresses per unit applied compression pressure. Resiliency is usually expressed in (% of original gasket height)/psi. A soft gasket would compress more than a hard gasket with the same applied pressure. Or stated the other way, a soft gasket would require less pressure than a hard gasket to compress the same % of gasket height. For instance a sponge neoprene gasket might compress 10% under an applied compression pressure of only 6 psi, but a solid neoprene gasket would require 50 psi for the same 10% deflection.

Minimum Pressure for Seal–As already stated, a gasket must at least make contact at the point of maximum separation between the mating surfaces (H_{max} H_g). Actually in most cases the pressure at this point must be a stated minimum in order to assure a seal. This would be rather easy to understand in the case of a high pressure hydraulic system. If there is not at least some required minimum pressure at the point of H_{max} the oil would blow by between the flange and the gasketing material. The pressure at H_{max} point must be high enough to prevent blow-by. For EMI gaskets this minimum pressure is determined by the pressure required to break through corrosion films and to make a suitable low resistance contact. For most EMI gaskets this is 20 psi, but can be as little as 5 psi.

Average Pressure–The average pressure applied to the gasket must also be large enough to compress the gasket so that the minimum gasket height subtracted from the maximum gasket height (which was determined by the minimum pressure required from the previous paragraph) is equal to the joint unevenness, that is $H_{max}-H_{min} = \Delta H$.



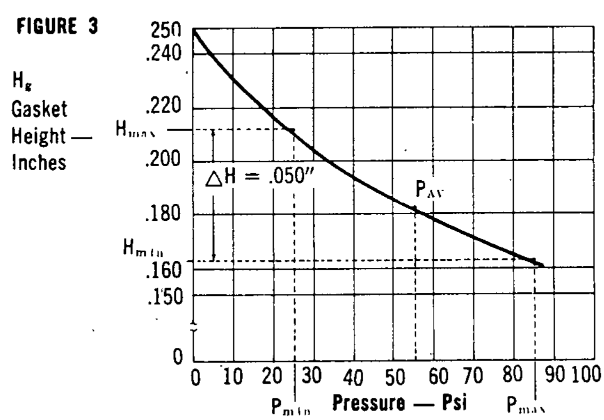


GASKET HEIGHT

To obtain the required seal from a gasketed joint, the gasket height must meet these criteria:

1. The pressure at point of maximum separation must be at least the minimum pressure to obtain the required seal.
2. The difference between maximum and minimum gasket compressed heights must be equal to the joint unevenness of the mating surfaces ($\Delta H = H_{max} - H_{min}$).

FIGURE 3

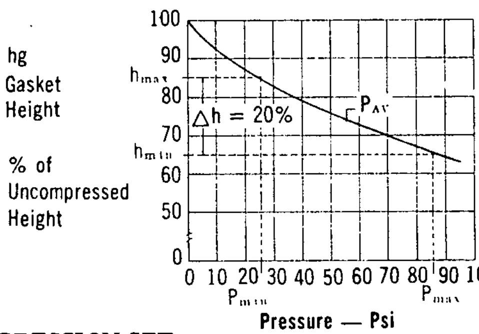


These principles are illustrated by reference to Figures 2 and 3. Figure 3 is the compression characteristic for the gasket material used in the joint illustrated in Figure 2. In this example the minimum pressure for a reliable seal is 20 psi. As shown, minimum pressure is actually 25 psi; the minimum pressure requirement has been met. Gasket height at this point is .212". Joint unevenness is .050" so the minimum gasket height is .212–.050 = .162. The second requirement has been met. From the curve, the pressure at this point is 85 psi. Average pressure is estimated by $\frac{P_{min} + P_{max}}{2}$ in this case $\frac{25 + 85}{2}$ = 55 psi.

Average pressure is important in estimating total force required to compress the gasket.

Gasket compression characteristics are most frequently given in terms of percent of gasket height so that one curve can be used for many actual gasket heights. Figure 4 is a plot of the characteristics shown in Figure 3 except heights are given in percent of gasket height. To distinguish actual heights from heights expressed in percent of gasket height, the latter are designated by lower case h.

FIGURE 4



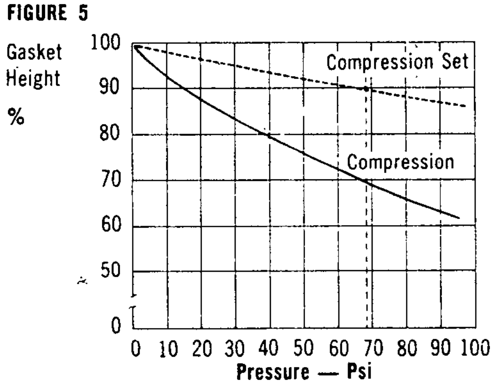
COMPRESSION SET

Some gasket materials take a compression set; that is, they do not return to original gasket height after compression. This is illustrated in Figure 5. The compressed height is indicated by the solid line. When compression pressure is removed, the gasket returns to the height indicated by the broken line. This is compression set. The importance of compression set depends on how the gasket is used.

CLASS A, PERMANENTLY CLOSED–If the gasket is used under a component that will, in all probability never be removed, the compression set is unimportant. It would show up only on disassembly. This type of joint is called "permanently closed" and identified as Class A.

CLASS B, REPEATED IDENTICAL OPEN-CLOSE CYCLES–Many gaskets are used in joints that are frequently opened and closed but always in the same manner (hinged door or symmetrical cover, etc.). In this case minimum compressed gasket height will always occur at the same place. This will also be the point of maximum compression set. In effect, original gasket height has been reduced at this point, but the gasket is still being compressed. For instance, Figure 5 shows compression and compression set characteristics for a gasket material (set is more severe than normal for emphasis).

FIGURE 5



CLASS C, COMPLETELY INTERCHANGEABLE–The problem of compression set is much more severe when there is complete freedom of positioning on repeat closures. A specific example would be a round gasket in a waveguide that might be removed and reused in almost any position relative to points of minimum and maximum compression. The compression set height at point of maximum compression may actually be less than minimum compressed height! It would therefore be possible to not make contact at all between gasket and mating surfaces at this point.

USING STANDARD GASKETS

The designer should know or estimate:

1. Joint unevenness.
2. Available compression.
3. Shielding required.

The object of EMI gasket design procedure is to fit the application requirements (joint unevenness, available compression forces, and shielding requirement) to the gasket characteristics (compressibility and EMI shielding capability).

Average Shielding Problems–In general the same reasoning outlined for maximum shielding will apply; choice of gasket material and contact surface is most important, pressure is secondary. If low frequency magnetic shielding is not a severe problem, then a minimum pressure of 5 to 20 psi may well be adequate. This reduction of minimum pressure can be very important because it increases the Δh (gasket compression range) significantly for the same average applied compression pressure.

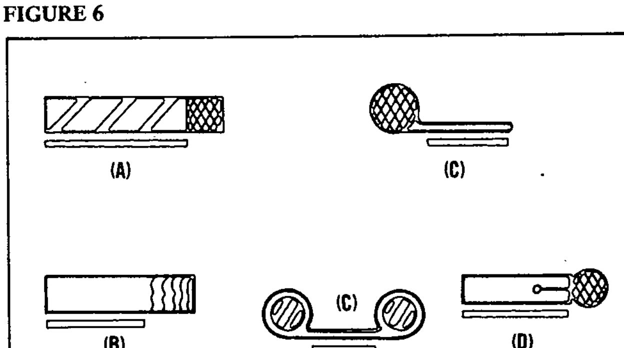
Minimum Shielding Problems–Especially when little or no low frequency magnetic shielding is required the minimum pressure could be as little as 1 to 5 psi.

Pressure Sensitive Adhesive–This is often the least expensive method for attaching EMI gasket materials; installation costs are often drastically reduced with only a slight increase in cost over a material without adhesive backing. As a matter of fact, most sales of sponge elastomer materials are for applications that do not require any pressure sealing; the adhesive backed rubber portion serves only as an inexpensive attachment method for the EMI portion!

In all cases the designer specifying non-conductive adhesive attachment must include adequate warnings in the applicable drawings and standard procedures for production personnel that the adhesive is to be applied **only** to the portion of the gasket material not involved with the EMI gasketing function. Experience teaches that installation workers will, either through carelessness or a misguided desire to do a better job ("This gasket would hold better if I glued all of it rather than half of it"), apply the non-conductive adhesive to the EMI gasket portion also. This will seriously degrade the EMI performance.

Bond Non-EMI Portion of Gasket–Since many very good non-conductive adhesives are now available, bonding a gasket product in position by applying the adhesive to the portion that is not the EMI gasket (which can be insulated from the mating surfaces by a non-conductive material) is often a very good way of mounting EMI gaskets.

FIGURE 6



Areas where non-conductive or dry-back adhesive can be used.

All aluminum EMI gasket products should be avoided since they make poor electrical contact. They should be used only when equipment specification explicitly require that only aluminum EMI gaskets be used against aluminum shields. Secondly, mating contact surfaces should be treated for best conductivity (tin coated, cadmium plated, conductive treatments of aluminum). Non-conductive protective coating such as paints and anodizing of aluminum are prohibited in all EMI gasket contact areas.

(The above material has been furnished courtesy of the Metex Corporation).

CONDUCTIVE ELASTOMERS

Electrically conductive silicone elastomers have, in the past eight years, achieved general popularity as EMI/environmental gaskets. By simultaneously protecting electronic packages against environmental corrosion and electromagnetic interference, they have become an essential tool of the electronic packaging engineer.

Correct application of conductive elastomers as EMI/environmental gaskets requires a knowledge and understanding of the material's behavior under load, the mating flange characteristics, the shielding requirements at each frequency, and the environment in which the package must function.

SELECTING THE RIGHT MATERIAL

Virtually all conductive silicones intended for EMI gasketing incorporate silver fillers in one form or another. Other fillers have appeared and disappeared, generally because of electrical instability (copper, tin), or poor shielding performance (carbon, nickel). Of the popular silver-bearing silicones, some use pure silver (and are therefore expensive) while others use silver-plated copper or silver-plated glass. The silver-plated copper fillers are granular in shape (which keeps them "locked into" the elastomer), and generally offer the best performance at the lowest cost. Their limitations are temperature (125°C continuous) and durometer (60-80 Shore A), but proper design can often neutralize the durometer problem.

When continuous temperatures above 125°C will be encountered, a pure silver or silver-plated glass filler is required. The silver-plated glass, although low in cost, is subject to electrical degradation under repeated mechanical loading (i.e., opening and closing the gasketed door or panel), and is not recommended for high-reliability military/aerospace applications.

Material density plays an important role in shielding performance. Generally the denser the material, the better the shielding. Of course, high density means high durometer, and the objective should be to use the highest-density material which will deflect enough to seal flange gaps. Often a dense, hard gasket can be made to seal effectively by proper selection of shape, size or flange design.

GASKET AND FLANGE DESIGN

Good shielding effectiveness requires low interface resistance across gasketed flanges. The best way to achieve low interface resistance is to design for as much metal-to-metal contact as possible. Conductive elastomer gaskets installed in grooves in one flange member allow this metal-to-metal contact (see Fig. 1), to a degree depending on how flat the flange surfaces are machined. This gasket approach has three other major advantages:

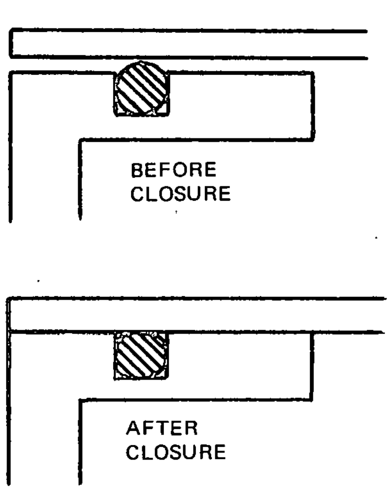


Figure 1: Grooves allow metal-to-metal contact

- The gasket can usually be in the form of a low-cost extrusion fitted around the groove
- Such extruded strips can have cross sections (round, hollow) which provide high deflection under modest closure force (under 10 lbs. per linear inch)
- The metal-to-metal contact provides a natural compression stop, protecting the gasket from damage caused by over-torqued bolts.

Conductive elastomer "0"-strip gaskets installed in grooves should be deflected 10-25% for best performance. The "D" gaskets should be deflected 5-15%. For example, a groove measuring .090" deep should take an "0"-strip gasket .100" to .120" high. Groove cross section area should be greater than gasket cross section area by about 5%. Of course, both the groove and gasket dimensions will have tolerances associated with them, and the designer must look at worst-case tolerance possibilities to make certain that the groove cannot be overfilled, or that the gasket cannot sit too deeply in the groove (see Fig. 2).

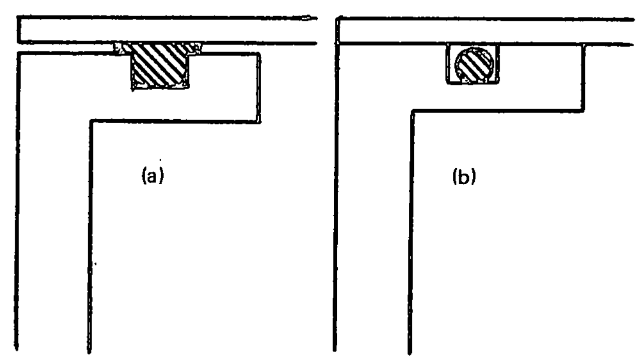


Figure 2: Obvious design errors—overfilled groove (a) and zero gasket pressure (b). Both conditions can result from tolerance variations not accounted for in design.

The gasket size will depend on the amount of deflection required or on the amount of closure force available. If flange stiffness, finish and flatness is such that gaps will be .010" maximum, a gasket height of .100" and groove depth of .080" should be selected (see Fig. 3). This should result in deflections between 10% and 20%. Remember that thin flanges will bow between fasteners, and this condition must be accounted for when determining maximum gaps.

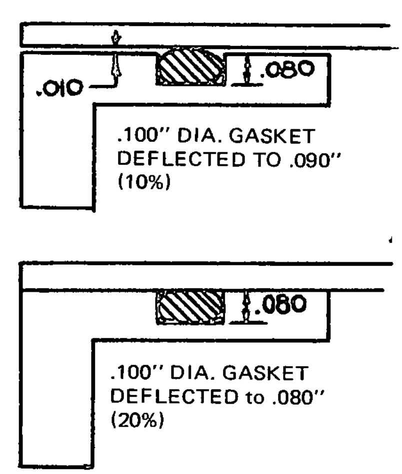


Figure 3: Groove depth of .080" and gasket diameter of .100" results in 10% deflection where gap is .010" (left) and 20% deflection where no gap exists.

Suppose a .100" gasket in the material selected requires more closure force to reach the maximum desired deflection than happens to be available? Figure 4 is a load-deflection curve for a .100" dia. "0"-strip in 60 durometer silver-plated-copper filled silicone. Notice that 20% deflection (.020") requires 6.5 lbs/inch of closure force. If the groove periphery happens to be 10", a total of 65 lbs of uniformly distributed closure force is required. If this force cannot be provided, three alternatives are available:

- Switch to a softer gasket material, such as a 40-durometer reticular structure (which requires only 4 lbs/in for 20% deflection of a .100" dia. "0"-strip). This would increase gasket price by about 25%.
- Switch to a larger gasket. For example, a .139" dia. "0"-strip (60 durometer) deflected 15% (.020") requires only 5 lbs/in. This would increase gasket price by about 45%.
- Switch to a hollow gasket. A .125" dia. hollow "0"-strip (60 durometer) will deflect 18% (.020") with only 2.7 lbs/in. Hollow gaskets generally cost the same or slightly less than solid gaskets of the same size, but are not available under .125" dia. In this case, therefore, there would be a gasket price increase of about 20%.

Shape plays an important role in grooved flange designs. For a given load, 0-strips will deflect more than D-strips of the same height. So, if closure force is marginal or limited, an 0-strip might work where a D-strip will not. An O-strip is also easier to install, because slight twisting will not affect the seal. Gaskets with flat sides (or bottoms) must be positioned correctly in the groove. When closure force is not a problem, D-strips provide a slight advantage in shielding performance. Since they are stressed higher than an equivalent-sized 0-strip under a given closure load, they will provide lower interface resistance across the gasket flange. A "D"-strip should also be used when groove dimensions (width or depth) rule out an "0"-strip. Generally, "D"-strips require closer groove tolerances to seal effectively. Other shapes (double "D", delta, rectangular, hollow "O" or "D", etc.) are useful in special circumstances, and are easily produced by extrusion.

Two other design considerations apply to extruded strip gaskets installed in grooves. The first is corner radii. To bend an extruded strip around a corner, the radius should be at least one-half the width (or dia.) of the strip. The larger the radius, the easier the installation. Molded gaskets do not have this limitation. When many corners, bends or complex groove layouts are required, one-piece molded gaskets will greatly simplify installation. Even square groove corners are acceptable if the gasket is molded with square corners.

The other consideration is strip ends–should they be spliced or merely butted? Again, the difference is one of installation ease. Spliced strips can be installed in a groove quite rapidly. Butting requires careful positioning to assure a reliable seal at the gasket ends. Installed properly, a butted joint will be just as effective as a spliced joint.

Gasketing Without Grooves

Many designers do not have the luxury of grooved flanges. Sheet metal enclosures, or enclosures too large to machine economically, must be gasketed by sandwiching a conductive elastomer strip or die-cut between the flange surfaces. Without metal-to-metal contact, the gasket becomes the sole path for conducting induced shield currents across the flange. For this reason, high gasket conductivity and electrical stability under repeated loading are essential.

When die-cut conductive elastomer gaskets are required, a good deal of design flexibility is lost. Die cuts, unlike extruded or molded "0" and "D" cross sections, can only be deflected about 10%. Strangely, the load-deflection characteristics of die-cut shapes is not always dependent on durometer. An .032"-thick 78 durometer material might deflect more under 100 psi than an .032"-thick 63 durometer material. Because these materials are *deforming* rather than *compressing*, shape plays a crucial role in their deflection behavior. Suffice it to say that most conductive silicon die-cuts deflect between 7% and 10% (maximum), and require at least 100 psi to reach even these modest deflection levels.

Translated into design terms, this deflection behavior means that very little joint uneveness can be compensated for by a thin die cut conductive silicone. It also means that close bolt spacing (under 3" for thick flanges, 1-1/2" for thin flanges) is generally required. For 1/8" flanges with 2"-3" bolt spacing, flatness would have to be held to within .005" for a .062"-thick die cut gasket to effectively seal the joint.

Where space permits, hollow strip gaskets with flat mounting tabs ("P" cross sections) can be used to provide more gasket deflection or to lower closure force requirements. Large door flanges, for example, can be effectively sealed and shielded with 1/4" dia. hollow "P" strips. The mounting tab can be bonded to the flange with either a nonconductive or conductive RTV adhesive. If a nonconductive adhesive is used, care must be taken to prevent it from squeezing under the hollow portion of the gasket (see Fig. 5) where it would electrically isolate the mating flanges. If desired, mounting tabs may be die cut with hole patterns and corner notches, and the strip can even be supplied spliced into a "picture-frame" ready for mounting.

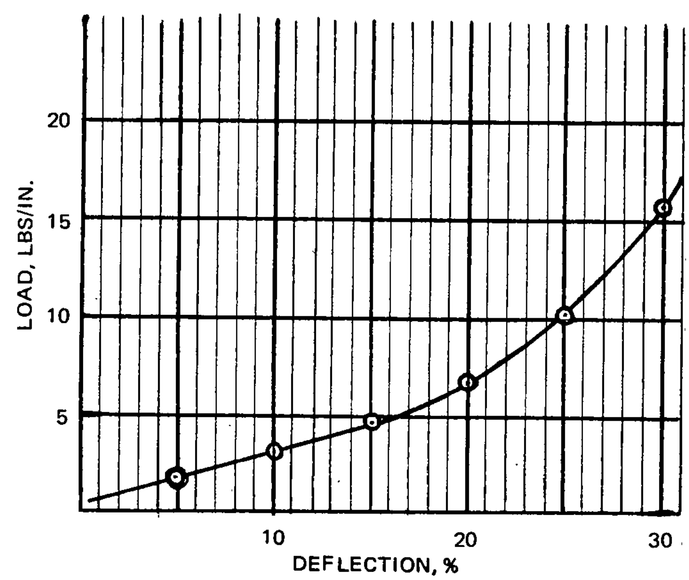


Figure 4: Load-deflection curve for .100" diameter "0" strip (60 durometer)

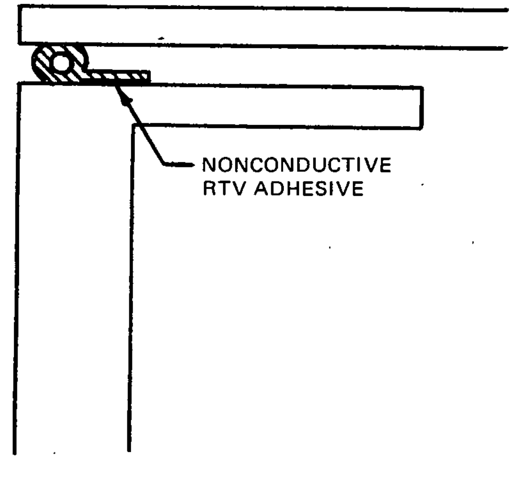


Figure 5: Mounting tab on hollow "P" strip bonded with nonconductive adhesive

Design rules for steel-rule-die-cut gaskets include the following:
1) Gasket thickness should have a tolerance of ±.004 (.020"-thick) to ±.010 (.125" thick).
2) Hole locations should have tolerances of ±.010".
3) Overall and cutout dimensions should have tolerances of ±.015" (dimensions below 10") or ±.020" (above 10").
4) Hole diameters should be 1/64" multiples, with tolerances of ±.010".
5) Holes should not be closer than the thickness of the gasket from any edge, otherwise hole breakout will occur. If this distance cannot be maintained, use slots instead of holes.
6) Internal corners should always be radiused.
7) Gaskets should be as thin as possible while still providing adequate deflection (.020" is generally a minimum thickness).
8) Whenever possible, compression stops should be provided to avoid over-compression of gasket material.

Compression Set

A major reason for designers' preference of conductive elastomers over knitted wire mesh gaskets is the material's ability to recover the major part of its deflection when the loading is removed. Typically, conductive elastomers exhibit only 2%-8% compression set after long-term loading at room temperature. An even more significant property is the material's stress relaxation behavior. This is the degree to which the material relaxes (i.e., stress level decreases) while it is loaded. Conductive silicones generally exhibit a stress decay of about 25%, all of which occurs during the first hour after the load is applied (see Fig. 6). By designing with this decay in mind, desired stress levels can be achieved and maintained without retorquing fasteners.

Outside edges of gasketed flanges, when exposed to severe salt spray environments, will develop a certain amount of galvanic corrosion. If such a condition on the outside of a flange is not tolerable, a simple finishing procedure will prevent it. Instead of masking off the entire mating flange surface (which must remain conductive) prior to applying the outside protective paint, mask in such a way that the paint is allowed to intrude about 1/8" into the flange. For grooved flanges, allow the paint to intrude to the midpoint of the gasket footprint. This procedure assures that salt-bearing moisture collecting on the outside edges or intruding into a flange outboard of a gasket groove will not see a silver-silicone/aluminum couple. Even 7 days of salt spray testing will not corrode flanges with this simple finish treatment. Of course, proper finishing of flange surfaces is crucial whether the gasket will be conductive or not. The only special requirement when RFI gaskets are used is that the flange surfaces be conductive.

Bare aluminum and magnesium, as well as iridited aluminum and magnesium, can be protected by properly designed conductive elastomer gaskets. The unfilled silicone gasket with oriented wires (which is not a "conductive elastomer," but is treated here because its intended function is the same—i.e., EMI and environmental sealing) often cannot protect the surfaces because the wires exhibit a "wicking" tendency, allowing moisture to be drawn onto the metal surfaces. In addition, these wires restrict the ability of the rubber to flow and seal.

The definition of a "safe" level of galvanic activity must clearly be expanded to include the requirements of the design. If all traces of corrosion must be prevented—inside and outside—the structure must be properly finished or must be made of materials which will not corrode in the use environment. In these cases, the outside edges of flanges sealed with conductive elastomers might also require peripheral sealing as defined in MIL-STD-1250, MIL-STD-889 or MIL-STD-454. MIL-STD-1250 deserves special mention, as it is very specific in relation to corrosion control methods applicable to enclosures.

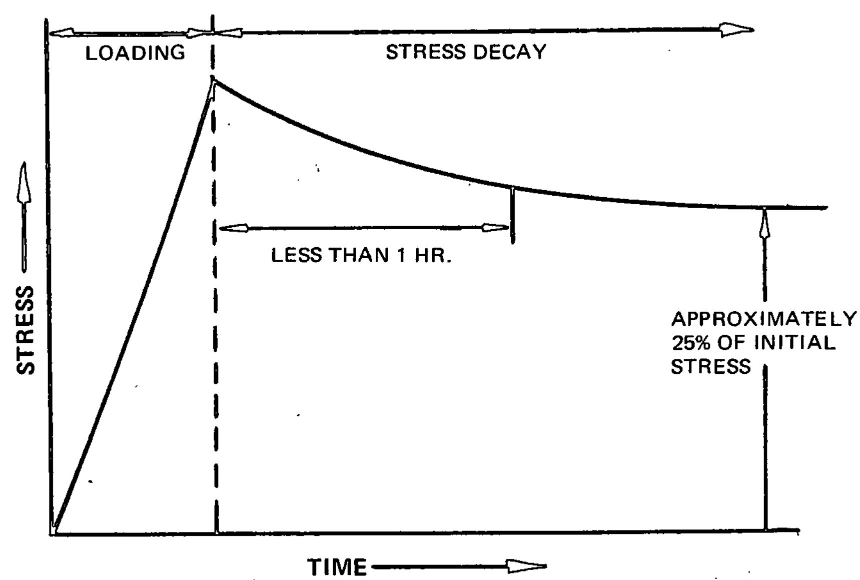


Figure 6: All rubber gaskets exhibit stress decay. Designer can compensate for it by selecting high initial stress level.

A Word About Corrosion

A common concern of designers is the potential corrosive effects of silver-bearing gaskets on aluminum or other non-silver flanges. Though not the subject of this article, it should be mentioned that comprehensive testing has shown silver-filled silicones to behave electrochemically quite differently than silver metal. From a design point-of-view, the key to preventing corrosion is to exclude moisture from the flange. A properly designed gasket and flange will remain free of moisture and corrosion.

The material on conductive elastomers was prepared by Bob Rothenberg of Chomerics, Inc. Reprinted with permission.

FINGER STOCK

Another form of EMI/RFI gasket used in many applications is contact fingers, often referred to as finger stock. They are available in various configurations including straight strips, corner strips and circular rings with inside or outside contact tips.

APPLICATIONS:

The fingers are most often used as a RF gasket where frequent access through the opening is required. They can be found around the periphery of most shielded room doors in parallel rows–two and three deep. Here, their wiping action as it is compressed, is a most desirable feature since it cuts through film and dirt which can build up along the mating surfaces. Figure 7 illustrates the wiping action of finger stock.

The fingers can also be used behind panels and drawers where it not only provides RF shielding, but also assures a good ground contact across the mating surfaces. Circular finger rings can be used to ground metal shafts where they penetrate a panel and protect against RF leakage. Their wiping action allows the shaft to rotate without appreciable drag.

CHARACTERISTICS:

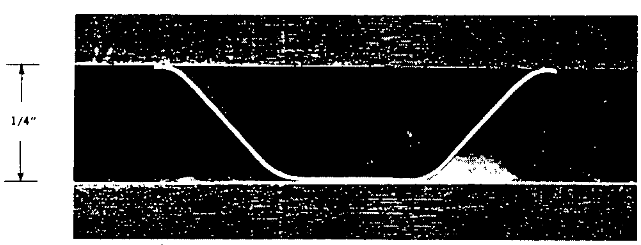
Finger stock is made of high-performance beryllium copper which has a relative electrical conductivity of 22 to 28. It can be purchased in many standard finishes including gold flashed, gold plated, silver plated, bright finish or as heat-treated ready for the user to apply the finish. The ring fingers are also available with localized deposits of silver or gold on the contact tips.

The finger strips feature a mechanically balanced design to provide high dynamic range, long endurance life and multiple lines of contact under relatively light pressure. Attenuation against electric fields of more than 100dB at 200kHz, 400kHz, 400MHz and 10GHz has been measured for a single rectangular enclosure.

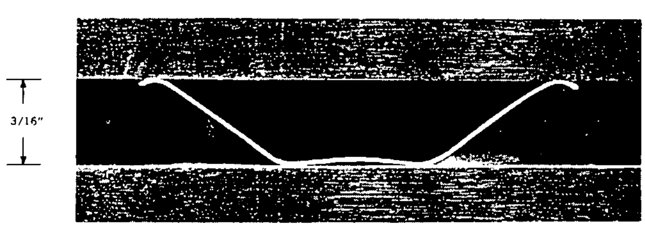
Finger stock can be fastened in place with rivets, clips, and epoxy or can be soldered. The newest technique is finger strips with a self-adhesive backing. Referred to as "Sticky Fingers" by Instrument Specialties, the pressure-sensitive adhesive was developed to provide an extremely tight permanent bond. The adhesive strengthens as it cures with age. Sticky fingers are unaffected in temperature ranges from -65°F. to 160°F. The adhesive also meets most salt spray, shock and humidity cycle tests.

To provide for an increase in the shielding effectiveness against magnetic fields, the sticky fingers can be furnished with a magnetic core insert. As an example, tests have shown that magnetic field shielding effectiveness has been increased from 14 to 18dB at 400Hz and from 46 to 59dB at 14kHz using the magnetic insert.

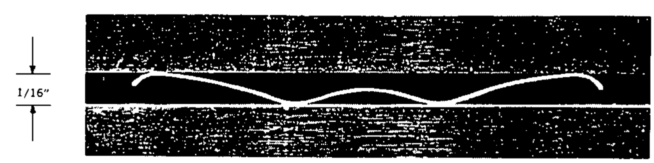
end views of linear gasket 97-436 compressed between flat surfaces



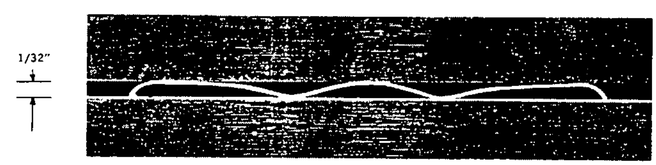
Three lines of contact occur when gap is 1/4". (Note: This photo was made after the gasket had been compressed to 1/64", and released.)



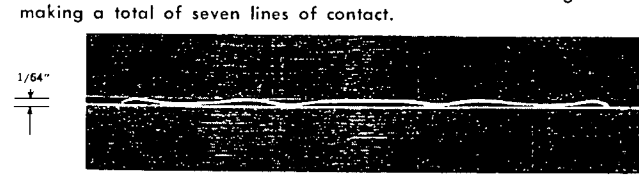
At 3/16" gap there are four lines of contact due to arching of center.



Note increased arching of center at 1/16" gap. This produces wiping contact with the mounting surface.



At 1/32" gap the tips of the fingers are in contact with the mounting surface, and the center arch is in contact with the closing surface, making a total of seven lines of contact.



At least nine lines of contact occur when the gasket is compressed to 1/64". (Note: Recovery from this deflection is excellent. See top illustration.)