Hybrid Hermeticity And Failure Analysis

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A study of hybrid packages has been conducted to establish the relationships, if any, between hermeticity defects and component failure. Research efforts focused on the structural analyses of packages. It has become clear that hybrid packages often are not capable of withstanding the tortures to which they are subjected in both manufacturing and application situations.

Hybrid packages on receipt were found to have been poorly inspected, poorly tested, often of very poor quality, expensive, and used to build unacceptable hybrids designed and built for critical, high-reliability, and frequently life threatening applications. Isolation of package problems was accomplished through leak testing, dye penetrant studies, and microscopic evaluation. The studies reported here covered hybrids from space hardware, various military defense systems, missile guidance systems, and some high-reliability commercial products. Approximately 500 defective packages were covered in this data.

Hybrid packages generally are quite expensive, built in rather limited quantity, and presumedly handled far more carefully than they are. Electrical failures in system applications using hybrids

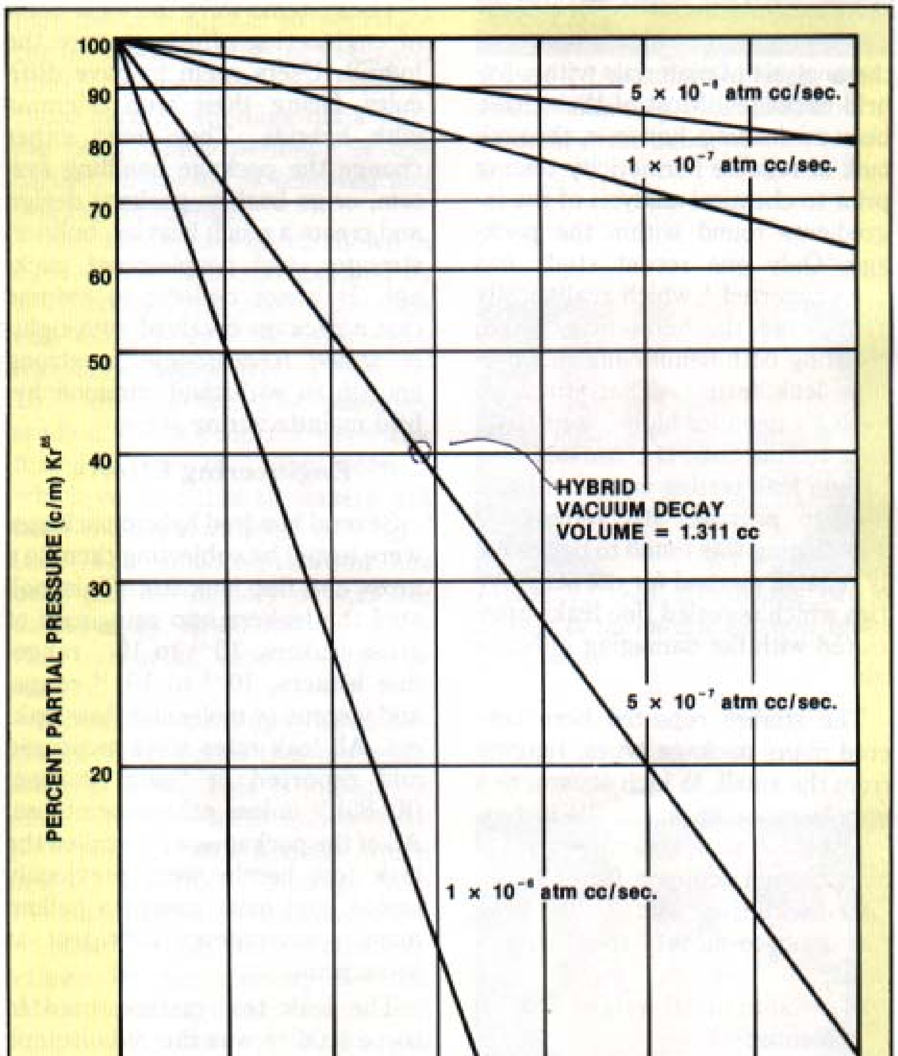

Figure 1, the typical decay of the partial pressure of Kr-85 within a part.

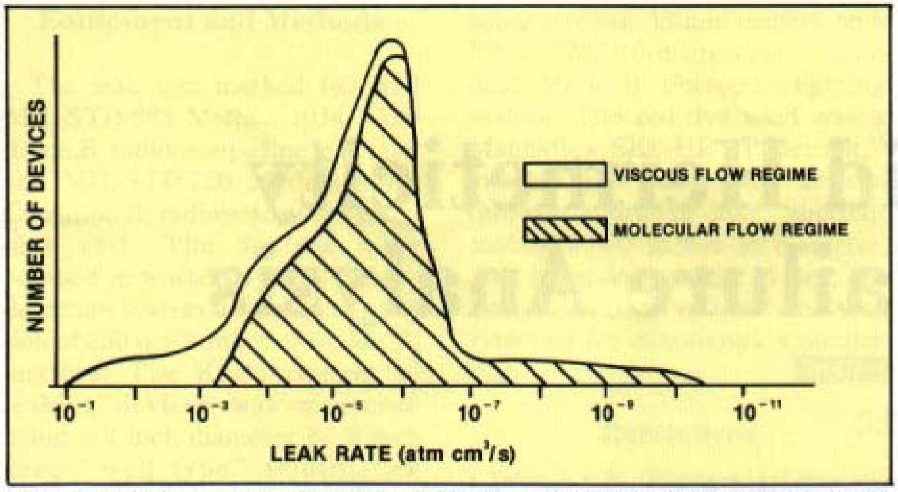

Figure 2, distribution of measured leak rates of all devices tested. Ten percent were for the range 10^{-3} to 10^{-4} atm. cm^3/s, 30 percent for 10^{-4} to 10^{-5} atm. cm^3/s, 50 percent for 10^{-5} to 10^{-6} atm. cm^3/s, 6 percent for 10^{-6} to 10^{-7} atm. cm^3/s, and 4 percent for $> 10^{-3}$ and $< 10^{-4}$ atm. cm^3/s.

prompted failure analyses which revealed corrosion within the packages. Many studies have covered the analysis of materials within hybrid packages. Most of these have been misleading, however, through lack of reliable hermeticity testing prior to chemical analysis of the ingredients found within the package. Only one recent study has been reported [1] which realistically approaches the hermeticity issue, covering both helium and radioisotope leak testing. That study revealed a need for higher sensitivity leak testing than the conventional helium leak testing equipment was able to provide, and radioactive leak testing was found to be the only reliable method for the sensitivities which revealed fine leaks associated with the damaging influx of air.

The studies reported here covered many package types, ranging from the small, ½ inch square, to a very large package, 2 × 2½ inches. All of these packages were seen to have certain common factors associated with their use:

- glass-to-metal feedthrough seals;
- metal-to-metal welded lids;
- plating;
- lead clipping;
- lead forming;
- lead soldering;
- testing; and
- human handling.

These items were the focal point of engineering efforts to save the hybrid. Users seem to have difficulty facing their true dilemma with hybrids. They must either change the package handling system, or go back to package design and create a much heavier, bulkier, stronger, and people-proof package. It is not realistic to assume that a package received with tightly sealed feedthroughs is strong enough to withstand common hybrid manufacturing steps.

Engineering Efforts

Several hundred hybrid packages were tested by subjecting them to a gross and fine leak test. This isolated the leakers into categories of gross leakers, 10^{-1} to 10^{-6} range; fine leakers, 10^{-5} to 10^{-10} range; and viscous or molecular flow leakers. All leak rates were measured and reported in "atm. cc/sec. (Kr-85)," unless otherwise stated. All of the packages which failed the leak test herein were previously tested, and most passed a helium mass spectrometer leak test at some point.

The leak test method used in these studies was the radioisotope leak test method, which uses radioactive krypton-85 gas in approximately 0.01 percent concentration with air. Ideally it is assumed that only pure dry nitrogen gas is used. However, chemical analysis has shown the gas content in the pressure bombing system will equilibrate with laboratory air in about six months.

The radioisotope leak test detects leaks by exposing the device to enough Kr-85 to enter the leaking part, providing a detectable amount of radiation to be measured emitting from within the non-hermetic package. The Kr-85 provides much higher detectability than other leak detection media, six to seven orders of magnitude more than the standard helium test. The hybrid with a 1 cc volume cavity at ambient pressure contains approximately 2.25×10^{19} molecules of air or nitrogen as sealed. That same package bombed in helium is expected to take in approximately 2.25×10^{18} molecules of helium (or 10 percent He), to satisfy the standard leak test equations. If the part has a leak rate of 1×10^{-8} atm. cc/sec., it will require 22 days at 75 psia of pure helium to satisfy the equations and introduce 10 percent helium into the part, the quantity assumed to be present when a mass spectrometer test is performed.

It should be pointed out that if the part contains only 5 percent He, the device will be undertested by a full order of magnitude[2]. Thus, the devices studied here were almost all found to be previously undetected leakers, due to a common lack of sufficient helium necessary for detection. The Kr-85 gas, however, requires only 5×10^{11} molecules for most reliable detection from within the part. The radiation emitting from a leaking part is directly related to the number of Kr-85 molecules which enter through the leak, which provides a direct calculation of the true leak rate of the device tested.

Most hybrid devices tested in these studies also were measured to establish the flow mechanism as either viscous or molecular flow, a step which requires only two tests. Some devices were additionally measured for "absolute leakage," a technique quite easily achieved with Kr-85. The leaking part was measured for Kr-85 content. It then was placed in vacuum overnight, removed, and the Kr-85 measured to establish the loss rate for the Kr-85. The absolute leak rate determination utilizes the equation:

$$P_t = P_o e^{-kt}$$

Where: P_t = partial pressure of Kr-85 at time "t"
P_o = original Kr-85 partial pressure
k = leak rate ÷ vol
t = time

With this equation, the absolute leak rate is easily verified by measuring the change in partial pressure of Kr-85 within the part. A plot of a typical decay is seen in figure 1. The percent partial pressure reduction is synonymous with reduction in counts per minute. Thus, a 1.311 cc volume cavity hybrid with a 5×10^{-7} atm. cc/sec. (Kr-85) leak will lose 60 percent of its partial pressure in 28 days. It should be noted that this loss of Kr-85 through a molecular flow leak occurs when the package is standing in air. Conversely, air is leaking into the device in a similar manner.

Leak Rate Distribution

Leak rates for all common package types have been studied to identify the sizes of leaks which normally are detected[3].

The bell distribution curve in figure 2 represents data from several million hermetic packages which were leak tested quantitatively, measured to establish molecular or viscous flow, and ultimately tested, in many cases, to a sensitivity of 1×10^{-10} atm. cc/sec. (Kr-85). One dominant factor was established through this study. Most of the leaking devices were found to have a molecular flow type of porosity leakage. Many of the leakers were found to be molecular-flow leakers, with total or cumulative leakage equal to a gross leak. This often is found to produce confusion when a leak rate of 5×10^{-5} does not produce bubbles by conventional bubble test methods. It should be realized that such a leak often is made up of perhaps 500 1×10^{-7} atm. cc/sec. porosity leaks, with each pore requiring infinite time to produce a visible bubble.

Once these leak test methods had been applied to the hybrid devices under study, the leaking packages were further studied to establish the cause for leakage.

Microscopic Examination

The leaking hybrids were examined microscopically at 6 to 40X to locate any abnormalities which could cause the part to leak. Nine defect or damage criteria were established, with all leaking hybrids showing at least one of the nine criteria.

Table 1 shows the results of the several hundred leaking hybrids compiled from these studies, rated for the percentage of the hybrids in each of the nine categories. It should be noted that many of the hybrids showed several of the failure criteria.

Handling: Undoubtedly the most severe damage found in the leaking hybrids studied was attributable to poor handling. Bent leads, broken glass, scratched gold plate, and the like all traced back to bad handling. Special carriers and handling fixtures reduced damage, but didn't always stop it. Figure 3 shows glass broken from lead bending on a 10^{-5} atm. cc/sec. leaking part. Ninety-five percent of the packages studied here showed evidence of poor handling in all of the nine categories.

Radial cracks: Seventy-five percent of the leaking hybrids studied were found to have radial cracks. These cracks commonly are generated from the pins outward 20 to 60 percent of the distance to the outer diameter of the glass bead. In a few instances the radial cracks reached the outer diameter of the glass, usually when the pin was eccentrically located. Two causes were associated with these cracks. The first was from directly applied side loading of the pins, in many cases due to fixturing. The second cause was due to lead forming which caused side loads.

A very special case was found with the rectangular pins used in hybrids. The photomicrograph in figure 4 shows radial cracks from

TABLE 1 — NINE MAJOR CAUSES FOR LEAKAGE

Handling damage	95%
Radial cracks	75%
Poor pin-glass bonds	60%
Meniscus chips	55%
Eccentricity	20%
Poor glass-header bonds	10%
Weld problems	10%
Inadequate glass	5%
Poor quality package	60%

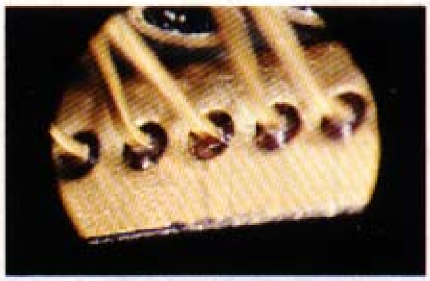

Figure 3, glass broken from lead bending on a 10^{-5} atm. cc/sec. leaking part.

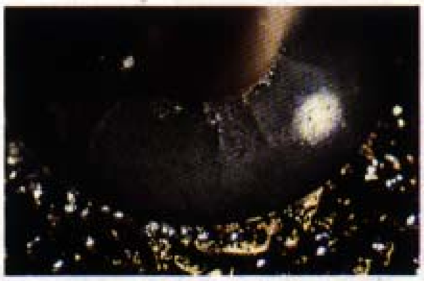

Figure 4, radial cracks from severe side loading of a very heavy pin.

Figure 5, a hybrid with 5 × 10^{-7} atm. cc/sec. leak rate in a brown glass header.

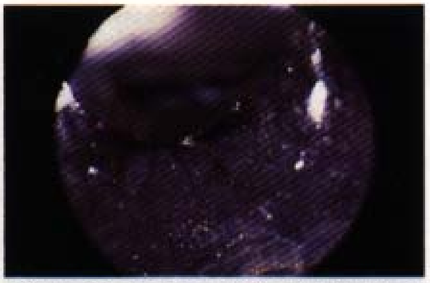

Figure 6, a header with a leak rate of 6 × 10^{-7} atm. cc/sec.

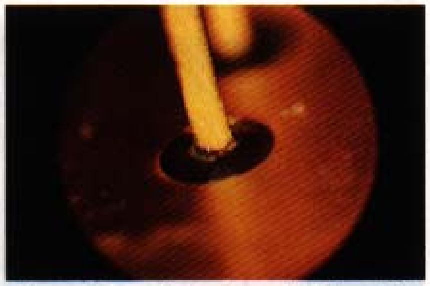

Figure 7, a circumferential break in the meniscus seal on 2 × 10^{-7} atm. cc/sec. leaking hybrid.

Figure 8, dye exiting through a thumbnail chip of a meniscus seal in a part with a 3 × 10^{-7} atm. cc/sec. leak rate.

severe side loading of a very heavy pin. The leak was 5 × 10^{-6} atm. cc/sec.

Figure 5 demonstrates a hybrid with 5 × 10^{-7} atm. cc/sec. leak rate in a brown-glass header. The leaks here were caused by sharp cornered rectangular pins following solder or tin-dipping steps. This phenomenon often is difficult to accept due to dependence upon the metals and glass having been chosen with very similar differential thermal expansions.

Figure 6 shows a photomicrograph of a header with a leak rate of 6 × 10^{-7} atm. cc/sec. It displays radial cracks using red dye injected into the leaking hybrid and then drawn out by placing the part in a vacuum. The leakage obviously follows the pin-glass bond to the surface. Due to the commonly achieved meniscus bond, the dye leaks to the surface through radial cracks.

Poor pin-glass bonds: The bond quality between the pin and the glass bead sometimes is hard to judge. The meniscus seal very often masks a poor bond at the pin-glass junction. Hundreds of headers were seen to pass the incoming "open package" leak test, using a two-sided helium leak test, and then all failed either the open-package helium leak test or a closed and sealed Radiflo test following the bending of the leads. This caused the meniscus glass to be broken.

Meniscus chips: The meniscus seal is the bond of the pin to glass which has flowed, or wetted, up the pin to a very thin circumferential glass-metal bond. Headers typically are found to be very dependent upon the meniscus bond. Figure 7 shows a circumferential break in the meniscus seal on a 2 × 10^{-7} atm. cc/sec. leaking hybrid. A small amount of red dye exists by traveling through a leaking pin-glass joint. Figure 8 shows dye exiting through a thumbnail chip of a meniscus seal in a part with a 3 × 10^{-7} atm. cc/sec. leak rate.

Eccentricity: The location of feed-through pins in the glass bead too often are assumed to be concentric, located in dead-center of the glass. Packages studied often were found to have been accepted even though the pins were located within a few thousandths of the edge of the glass bead. Often, eccentrically located rectangular pins were found to cause leaks, as seen in figure 9. This type of structural defect rarely withstands a thermal shock such as a solder dip, which forces a sharp corner of a pin against a very small quantity of glass and produces leakage.

Poor glass-header bonds: Bonding of the outside diameter of a glass bead generally is quite good in hybrid packages. This study revealed leakage developing at the outside diameter of the glass along 10 to 20 percent of the circumference directly adjacent to the weld, as seen in figure 10. This example shows one of six leaking glass beads on a 12 pin package. All of these leaks were easily seen with red dye. Over 50 percent of the hybrids in one lot leaked, and every package had at least one outer diameter glass leak.

Figure 11 shows red dye coming out of leakage at the outer diameter of the glass beads. Additional leakage between the pin and glass also was seen in some of the packages in this group of leaking hybrids. These hybrids also showed damage from bad handling, with bent leads, chipped meniscus, eccentricity, and non-planar pins. The meniscus breakage and radial cracks found in this group were traced to fixturing which held the leads in a vise-like holder close to the package. The package manufacturer permitted leads to sag out of a single plane, with as much as a 0.020-inch misalignment. Many leaks were generated during the lead-forming steps where misaligned leads are tightly held for forming.

Weld problems: Defects were found in some of the hybrid welds which caused rather large leaks, in the 10^{-5} to 10^{-6} range. One weld was determined to be a start and stop point without adequate overlap. Many other weld leaks were found, with a variety of causes. Approximately 10 percent of the leak-

Equipment and Methods

The leak test method followed MIL-STD-883 Method 1014, Condition B, radioisotope fine leak test; and MIL-STD-750 Method 1071, Condition B, radioisotope dry gross leak test. The devices were bombed in a Radiflo Mark V leak detection system with a concentration of 250 uci/atm. cc of Kr-85/N_2 mixture. The Kr-85 content of leaking devices was measured using a 2 inch diameter by 3 inch deep "well type" scintillation crystal, and/or a 4 inch cubical "flat top" crystal for very large hybrids.

Photomicrographs were obtained using a Nikon 35 mm camera on a Nikon SMZ-10 microscope, with a dual Mark II fiberoptic lighting system. The red dye used was a Magnaflux SKL-HF "Penetrant," injected into the leaking devices through a drilling hole, approximately 0.060 inches in diameter. The holes were solder sealed, the device placed in vacuum, and then removed for microscopic examination. **HCT**

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