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PROCESS EFFECTS ON HIGH VOLTAGE
ELECTRICAL ASSEMBLY PERFORMANCE

By D. A. Cummings

Published August 1978

Final Report

Prepared for the United States Department of Energy
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**Kansas City
Division**

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Manufacturing processes and package configurations that affect the operation of some high voltage electrical assemblies have been evaluated. High voltage breakdown, adhesion problems, and encapsulated component and solder joint breakage have been relieved by improvements in residue analysis, cleaning and coating techniques, and stress relief coatings. A quantitative comparison of encapsulated lead stress relief systems has been completed to determine their effect on both component and solder joints during thermal cycling of encapsulated electronic assemblies. Evaluations have been conducted involving printed circuit board substrates with thermal expansion equal in all directions. A qualitative solder joint thermal cycle study was conducted to compare the effects of encapsulant, lead loops, and sleeving on solder joint failure.

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A prime contractor with the United
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SUMMARY

The processes involved in fabrication of some parts include soldering electronic components to printed circuit boards; stress relief forming and sleeving component leads; conformal, stress relief, and high voltage hold-off coating, and mass encapsulation. Design requirements for high reliability, long life, and failure free performance after exposure to rigorous g-forces and thermal environments have created the need for better control of the processes.

This work investigates three specific problems: mass encapsulant cracking because of mismatches in thermal coefficients of expansions in adjacent materials, electronic component and solder joint damage associated with thermal cycling of mass encapsulated assemblies and high voltage breakdown.

Seven special evaluations were conducted. Each evaluation culminated in a separate topical report. Subjects covered on these reports include cleaning procedures, the effects of coating and cleaning on corona and high voltage breakdown, syntactic polysulfide conformal coatings, syntactic polysulfide stress relief coatings, printed circuit board substrates, stress relief techniques for reducing thermal fatigue in solder joints, and quantitative evaluations of component stress relief bends in encapsulated electronic assemblies.

These efforts resulted in several significant accomplishments.

- The effectiveness of the cleaning and handling procedure was verified. This verification indicates that the three solvent spray method (alcohol, trichloroethylene, and Freon) for cleaning assemblies prior to mass encapsulation or high voltage coating provides an excellent process for guaranteeing adhesion and preventing cracking or high voltage breakdown.
- Cleaning the high voltage bond surface and evacuating the coating before application improves the level of resistance to corona and high voltage breakdown.
- A phenolic microballoon syntactic polysulfide conformal coating developed as a result of this effort has been incorporated into the production of several different assemblies potted in glass microballoon-epoxy and urethane foam. Data supplied has been used for calculations which support the incorporation of syntactic polysulfide in these applications. The data has also been used to calculate specific coating thicknesses for components.

- To match the thermal coefficients of expansion of different substrate materials which are being mass encapsulated, materials such as ortho-diallyl-phthalate and glass microsphere filled epoxy were tested as replacements for the standard glass laminate and epoxy process. Although the new materials could be successfully copper clad, the process now used to convert the clad material into a functioning circuit board is damaging to the substrate.
- An evaluation of techniques for reducing thermal fatigue in solder joints indicated that sleeving is the most effective technique for protecting solder joints in thermal-cycled foam-encapsulated electronic assemblies. Other material configurations were tested and quantitative data was developed to permit the comparison of component as well as solder joint protection.

DISCUSSION

SCOPE AND PURPOSE

Some electronic assemblies must functionally survive high g-forces (500 to 5000 g's), vibration, and long term thermal cycling (-18°C to $+71^{\circ}\text{C}$) while generating and containing high voltages (2 to 6 kV). This effort was begun to identify and study manufacturing processes and package configurations that impact operational performance of these units. Specific problems involved broken glass and ceramic high voltage switches as a result of encapsulation stresses, high voltage breakdown in vacuum testing as a result of poor material adhesion, and component and solder joint damage in thermal cycling as a result of inadequate stress relief protection.

ACTIVITY

An evaluation of cleaning procedures was undertaken to compare the procedures used by Bendix with those proposed by the design laboratory. The project involved the study of contaminated surfaces, methods for removing contaminants, and an evaluation of bond strength tests and evaporative rate analysis.

A study of corona and high voltage breakdown involved an investigation of the effects of the vacuum processing of coating materials and printed circuit board surface cleaning procedures. The types of contaminants involved at the material interface were examined, the methods of coating application were evaluated, and various coatings were studied to determine a practical approach to minimizing corona.

A study of syntactic polysulfide conformal coatings reported on the program designed to measure the degree of compression of thin (0.254 to 0.762 mm) coatings of polysulfide sealant and the various microballoon filled syntactic modifications of this material.

A study of syntactic polysulfide stress relief coatings included an examination of material formulations and coating processes required to adequately protect electronic assemblies from stress concentration caused by glass-microballoon-filled-epoxy mass encapsulation.

A printed circuit board substrate evaluation encompassed four areas: using the encapsulant as a core material, using filled molding components as core materials, making quasi-conventional laminate from fabrics with greater Z-directional stability, and

wiring around a disappearing matrix. This effort was directed toward developing a printed circuit board substrate material whose three-dimensional thermal expansion properties matched those of the mass encapsulant.

A study of techniques for reducing thermal fatigue in solder joints was based on an empirical study in which specially designed printed wiring assemblies were thermal cycled. The results of this study were then used to compare solder joint failure rates and to recommend a packaging technique.

A quantitative evaluation of component stress relief bends in encapsulated electronic assemblies compared four component lead configurations in three encapsulants. Loads were introduced to test specimens and quantitative comparisons were made for both solder joint and component body stress relief.

The overall effort centered around coordination of each effort to maximize its contribution to the scope and purpose of the project.

ACCOMPLISHMENTS

Cleaning Procedures

Alternate cleaning procedures have been evaluated on three different substrates using strength tests and evaporative rate analysis as methods for comparative analysis. Verification was made of the procedure for cleaning and handling. Sandblasting was identified as an operation that needs more control.

Effects of Coating and Cleaning on Corona and High Voltage Breakdown

The investigation of corona and high voltage breakdown in conformal coatings resulted in the following information.

- Corona effects caused by ionization of gas filled bubbles in coatings have been identified in terms of corona start voltage.
- A vacuum method was determined to be effective in minimizing bubbles in coatings prior to the coating operation.
- Surface contaminants at the printed-circuit-board-to-coating interface decreased the level of corona starting voltage and increased hi-pot failures.
- A controlled cleaning cycle that reduces surface contamination was found to increase the level of corona start voltage and to reduce the number of hi-pot failures.

- Data concerning corona degrading effects in the assemblies studied and their possible influence on neighboring resonant circuits was tabulated. This information is useful in reviewing design layouts, material requirements, and manufacturing processes related to high voltage packaging.

Syntactic Polysulfide Conformal Coating

Phenolic microballoon syntactic polysulfide conformal coating has been incorporated into the production of several units currently potted in glass microballoon epoxy. Data supplied as a result of this effort has been used for calculations which support the incorporation of syntactic polysulfide and to calculate coating techniques for specific components. The test specimens devised during this project, although less than perfect, are considered useful for determining the modulus of candidate conformal coating materials.

Syntactic Polysulfide Stress Relief Coating

Data resulting from this study indicate that material age and the addition of phenolic microspheres reduce the pot life of syntactic polysulfide. Procedures were developed for the use of syntactic polysulfide on the several different parts. It was found that the addition of 10 to 15 percent toluene to the syntactic polysulfide made it easier to brush on. This work also showed that there is an advantage to using molded "boots" to provide good coverage along with the second coating of red pigment. This evaluation casts doubt on the need for moisture in the cure mechanism of polysulfide and supported the conclusion that adequate time and temperature (2 hours at 71°C) are required to cure the material.

Printed Circuit Board Substrates

This study showed that substrate materials such as DAP and epoxy-glass microballoons can be used successfully to make a clad material, but that the processing necessary to convert the clad material into a circuit board is potentially damaging. Transfer molded epoxy was molded into terminals and hard wire components and appears to be the most usable of all systems because it bypasses the problems associated with bonding the copper sheet to the substrate material. The idea of special fabrics or felts for laminates is still a viable concept despite the history of procurement problems. A recent development in 0.254-mm-thick fiberglass mats may be applicable to this area, particularly since felt type materials were unavailable at the start of this evaluation. Specialty fabrics are receiving increased attention from other agencies within the government.

Reducing Thermal Fatigue in Solder Joints

It was determined that the most effective solder joint stress relief technique for the polyurethane foam encapsulant used on two parts is silicone sleeving over the component lead wires. The use of 128 kg/m³ rather than 320 kg/m³ foam is advantageous only when there will be no sleeving over the component lead. It was also found that the use of special lead configurations offers no additional protection to solder joints over the standard 90-degree bend.

Component Stress Relief Bends in Encapsulated Electronic Assemblies

The results of this study can be used to select the optimum stress relief loop style and sleeving for an encapsulated electronic assembly. Although silicone sleeving may have the lowest resultant stress level, polyolifin is extremely close and a wise choice because of the ease of processing. In addition, component-lead-to-body qualification tests can be set to guarantee that the component can survive the next assembly encapsulated environment. Similarly, having the predicted load data for an encapsulated stress-relief-protected solder joint can allow the calculation of the predicted thermal fatigue in the solder and establish a basis for a long life solder joint system. Information gathered during this effort has contributed to the selection of stress relief techniques and processes for a wide variety of applications.

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