STRESS ANALYSIS OF HYBRID PINS IN A WARPED PRINTED WIRING BOARD USING MSC/NASTRAN

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ABSTRACT

During manufacturing, when the hybrids are wave soldered on a plated-through hole printed wiring board, the heat effects cause the polyimide board to warp. Since the hybrids are rigid, any attempt to straighten the edge of the board will introduce the residual stresses in the pins of the hybrid. This paper presents finite element modeling of such an out-of-plane imperfection of the board. The stress analysis is performed to estimate the residual stresses in the hybrid pins using MSC/NASTRAN. Also, a chassis level random frequency response analysis is performed to show the use of excursion delimiter in reducing the vibration-induced deflections in the board.

INTRODUCTION

The electronic unit (EU) of the missile is comprised of individual chassis, a housing, and a motherboard. An individual chassis has a printed wiring board (PWB) with various components mounted on it. They include several modules commonly referred to as hybrids. One of the common methods of mounting the hybrids is through-the-board mounting using the conventional mass soldering technique, known as wave soldering (reference 1). During manufacturing, when the hybrids are wave soldered on a plated-through hole PWB, the heat effects cause the polyimide board to warp. Since the hybrids are rigid, any attempt to straighten the edge of the board will induce residual stresses in the pins of the hybrid. A stress analysis of such a warped chassis board of the missile is presented in this paper. The residual stresses in the hybrid pins are calculated using the single-point constraint displacement (SPCD) feature of the MSC/NASTRAN. Also, a chassis level random frequency response analysis is performed to show the use of excursion delimiter in reducing the vibration-induced deflections in the board.

PROBLEM DEFINITION

A typical PWB used in the missile is shown in figure 1. When installed in the chassis, a mechanical support is provided on the board edges AB and ED through the card guide and on edge AE by a slot provided by the housing. The connector is located along the edge BC. During the soldering process, these edges were constrained so that the board can be installed in the chassis. However, the edge CD was not constrained and, as a result, this free edge was bowed out of the plane of the board (figure 2). To straighten the unsupported edge of the PWB, an edge restraint was provided. The edge restraint was added to the EU housing to support the free edge of the PWB and was configured as a channel section lined with a silicone rubber extrusion of "U" shaped cross section (figure 3). However, this method of straightening the PWB resulted in failures of the pins of the hybrid near this edge (designated as hybrid number 4 in figure 1). Since the hybrid is rigid compared to the polyimide board and the hybrid pins are firmly mounted on the board, the hybrid pins near this edge (figure 4) were severely stressed. The middle pins of this hybrid (along the free edge) were in compression, and the end pins were in tension. A static analysis is performed to estimate these residual stresses in the pins.

Also, a chassis level random frequency response analysis is performed using the appropriate vibration input profile. The chassis level test of the PWB is simulated using MSC/NASTRAN. In addition, analysis is also performed with the excursion delimiter to show its effect on the board level deflections.

ANALYSIS

Finite Element Model. MSC/NASTRAN finite element computer program is used to perform structural analysis of the PWB. The polyimide board is a composite plate made up of several layers. It was modeled as a single layer thickness plate with equivalent properties. The plate/shell finite elements, QUAD4, were used to model the polyimide board and the hybrids. The beam elements, BEAM, were used to model the hybrid pins. The material properties used in the analysis are listed in the appendix. The entire model consisted of 754 plate elements and 100 beam elements. The finite element model of the entire PWB is shown in figure 5. The material properties used in the analysis are listed in appendix. These properties were obtained from reference 2. The finite element model was validated by comparing the modal responses.

Static Analysis. The measurements of the maximum bow along edge CD ranged from 0.04 inch to 0.1 inch. Since the topography of the warped card was not available, the measured bow distance at the center of edge CD was used to estimate the physical condition of the card. The out of plane coordinates were determined using this distance at the center of the edge CD and assuming a linear variation to the corners C and D. Also, it was assumed to vary linearly from the edge CD to the other side of the card (edge AE). Four different finite element models were prepared using the maximum bow distances of 0.04 inch, 0.06 inch, 0.08 inch, and 0.10 inch.

The coordinates of each nodal point were based on the maximum bow distance. The finite element model with the warped geometry is shown in figure 6.

The channel support was provided to straighten the warped edge CD. It essentially took the curved edge and made it straight. This was simulated by using the single point constraint displacement (SPCD) features of the MSC/NASTRAN (reference 3). The SPCD command can be used to apply the enforced displacements at the nodal points. In this analysis, a load case is created using the SPCD commands to move the nodal points on the edge CD from their bowed position to the straight position.

Two sets of calculations were performed: assuming the channel provided a perfectly straight support along edge CD, and the compressibility of the silicon rubber within the channel kept the edge CD bowed 0.021 inch (figure 7). In the first set of calculations, the nodal point constraint displacements were applied such that the nodes on the edge had zero out-of-plane deflection. In the second set of calculations, the compressibility of the silicone rubber was taken into account using the maximum compression set value of 25 percent according to Federal Specification ZZ-R-765E. The finite element models were built for the maximum bow values of 0.04 inch, 0.06 inch, 0.08 inch, and 0.10 inch at the center of the edge CD. The analyses were performed for both the channel support conditions. The pin 1 of hybrid 4 of figure 1 experienced the maximum tensile stress. The results are summarized in table 1.

Table 1. Stresses in pin 1 of Hybrid Number 4 (Units: Pounds per Inch^2)

Maximum Bow Distance (Inch)	No Compression Set	Maximum Compression Set
0.04	36,000	20,000
0.06	54,410	37,380
0.08	76,010	59,110
0.10	94.,900	78.,760

The hybrid pins were made of Kovar material. The yield stress of the material is 50,000 psi, and the ultimate stress is 75,000 psi. The analysis results show significant build up of the residual stresses in the pins due to straightening of edge CD. Depending on the amount of bow due to warping of the board, some of the pins of the hybrid may either yield or reach failure stress.

Dynamic Analysis. The design of the PWB which is subjected to vibrations while in service requires special considerations. The vibration-induced failures in the PWB assemblies may occur due to excessive board deflections. In this section, MSC/NASTRAN is used to perform the vibration analysis of the PWB.

A dynamic response analysis is performed to estimate the stresses in the pins due to in-flight vibrations. MSC/NASTRAN is used to perform frequency response analysis of the PWB. A vibration profile of a typical chassis level test of the PWB is used as an input (reference 2). The finite element model of the flat PWB geometry was used in the analysis. The PWB was mounted on a rigid plate, and input acceleration was applied to the rigid plate during the chassis level test (figure 8). This test was simulated using the "large mass" method of MSC/NASTRAN (reference 4). A rigid plate was modeled as a large concentrated mass, and the rigid body elements, RBE2, were used to connect the rigid plate to the PWB. The input acceleration power spectral density (PSD) used in the analysis is shown in figure 9.

The modal frequency response analysis using Solution 111 of MSC/NASTRAN was performed. The plot of acceleration PSDs at the center of the board and, at the location of the pin 1 of hybrid 4 (identified as nodal points 120 and 226, respectively, in figure 8) are shown in figures 10 and 11, respectively. The stress response of the pin 1 of hybrid 4 is shown in figure 12. The pin encounters the peak stress of 4,800 psi.

To reduce the vibration-induced deflections, a common practice is to place an excursion limiter of an elastomer material, commonly known as snubber, to act as a damper to limit the vibrations of the board. Besides reducing the maximum deflections in the board, and thus reducing the stresses in the pins, it also can shift the fundamental frequency of the board. In this analysis, a snubber was modeled in the center of the PWB. Since the snubber acts as a damper, it was modeled using the ELAS2 element of the MSC/NASTRAN. For the sake of illustration, a snubber having an equivalent stiffness property of 100 pounds per inch was used in the analysis. The analysis results showed that the peak stress in the pin 1 of the hybrid 4 was reduced to 3,686 psi. The peak deflection response in the center of the board was reduced by 39 percent. The fundamental frequency of the board was increased by 8.2 percent. The peak acceleration PSD at the center of the board was reduced by 58 percent and the Grms was reduced by 31 percent.

SUMMARY

The MSC/NASTRAN is used to perform the stress analysis of the warped PWB. The structural analysis is performed for various bow conditions to determine the stresses induced in the hybrid pins when the channel support is inserted on the free edge of the PWB to straighten it. The analysis shows such a solution can introduce significant stresses in the pins of the hybrid. Depending on the amount of bow and the compressibility provided by the channel support, the pins either fail instantaneously or have significant residual stresses on them. For the flat PWB, the stresses in the hybrid pins induced by the typical vibration profile are much lower than the yield strength of the material. The vibration analysis with the snubber in the center of the board shows that the peak deflections in the board can be controlled, and the failures in the PWB assemblies can be avoided.

ACKNOWLEDGMENTS

The work presented in this paper was in part supported by the YA Joint System Program Office at Eglin Air Force Base, Florida.

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[2] Raytheon Company, Missile Systems Laboratories, " LS Hybrid Pin Failures - Root cause Investigation Summary Report", June 1992.

[3] *MSC/NASTRAN User's Manual, Version 66,* The MacNeal-Schwendler Corporation, Los Angeles, CA, November 1988.

[4] *MSC/NASTRAN Handbook for Dynamic Analysis. Version 63,* The MacNeal-Schwendler Corporation, Los Angeles, CA, June 1983.

APPENDIX

Material Properties Used in the PWB Finite Element Model

Nomenclature

E = Modulus of Elasticity
t = Thickness
D = Diameter

ν = Poisson Ratio
ρ = Density
psi = pounds per inch^2

Mechanical Properties

1. Polyimide Board

$E = 2.5 \times 10^6$ psi
$\nu = 0.12$
$t = 0.06$ inch
$\rho = 0.060$ lb/in^3 (Unloaded)
$= 0.283$ lb/in^3 (Loaded)

2. Hybrid Plates -Kovar

$E = 20 \times 10^6$ psi
$\nu = 0.3$
$t = 0.1455$ inch
$\rho = 0.225$ lb/in^3

3. Hybrid Pins - Kovar

$E = 20 \times 10^6$ psi
$\nu = 0.3$
$\rho = 0.225$ lb/in^3
$D = 0.018$ inch

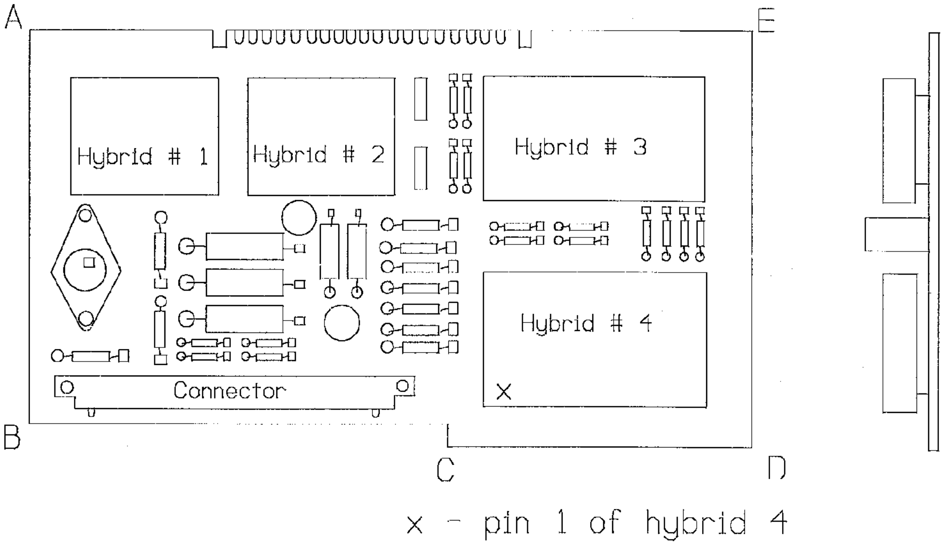

Figure 1. Schematics of Printed Wiring Board

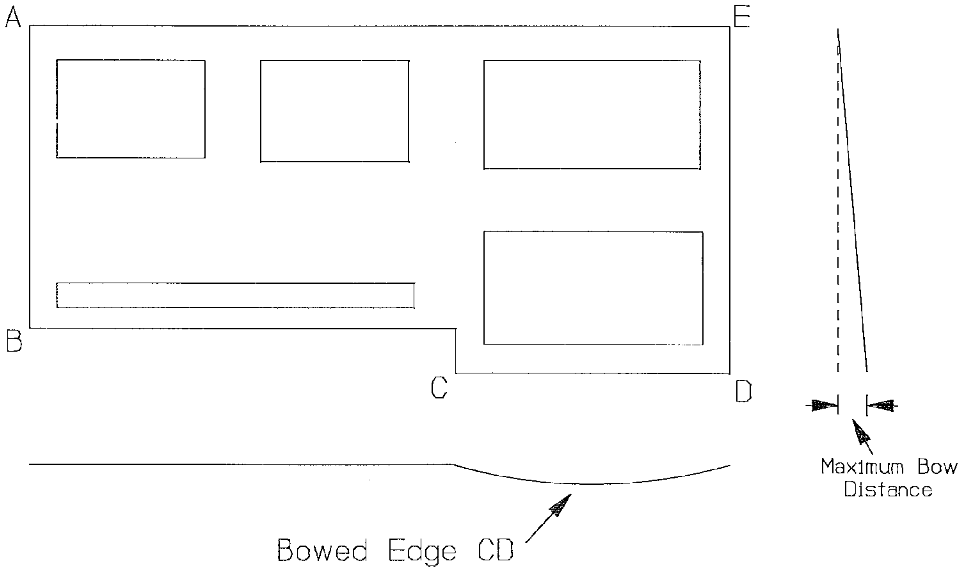

Figure 2. Bowed Printed Wiring Board

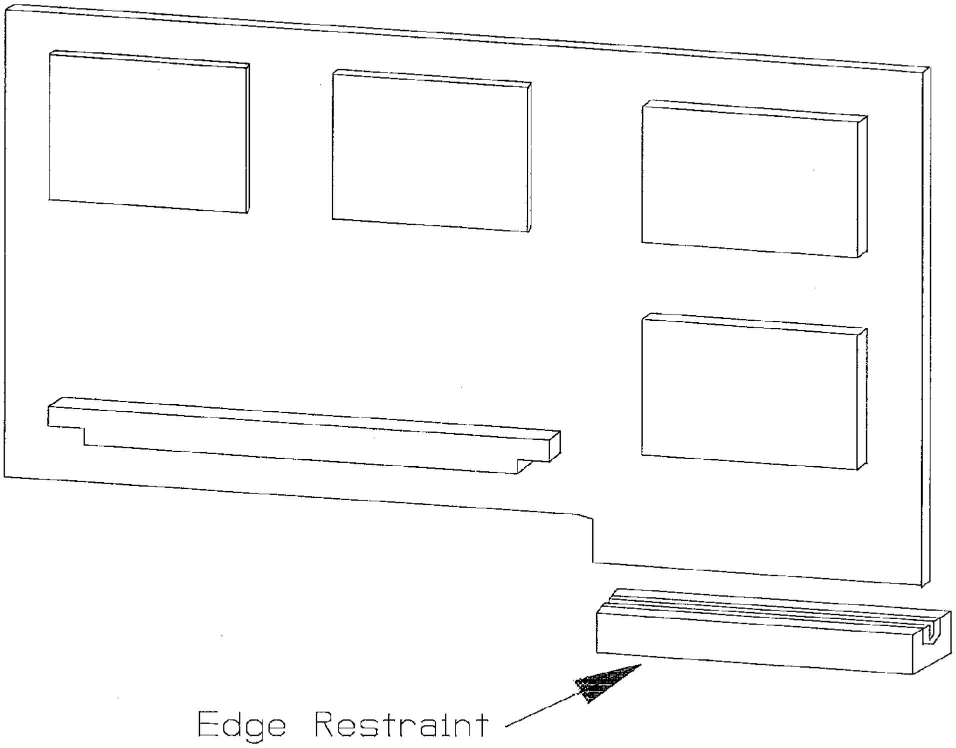

Figure 3. PWB with Channel Support

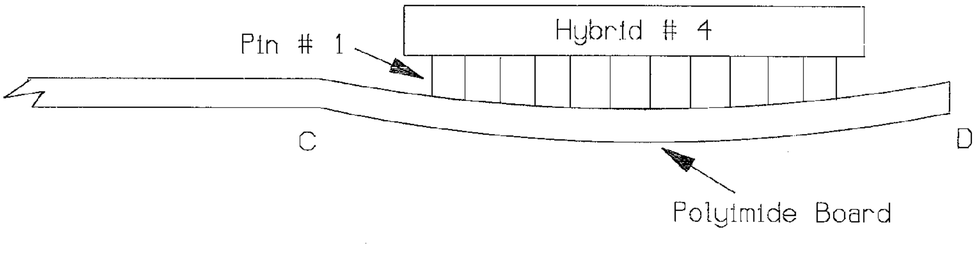

Figure 4. Warping of Edge CD

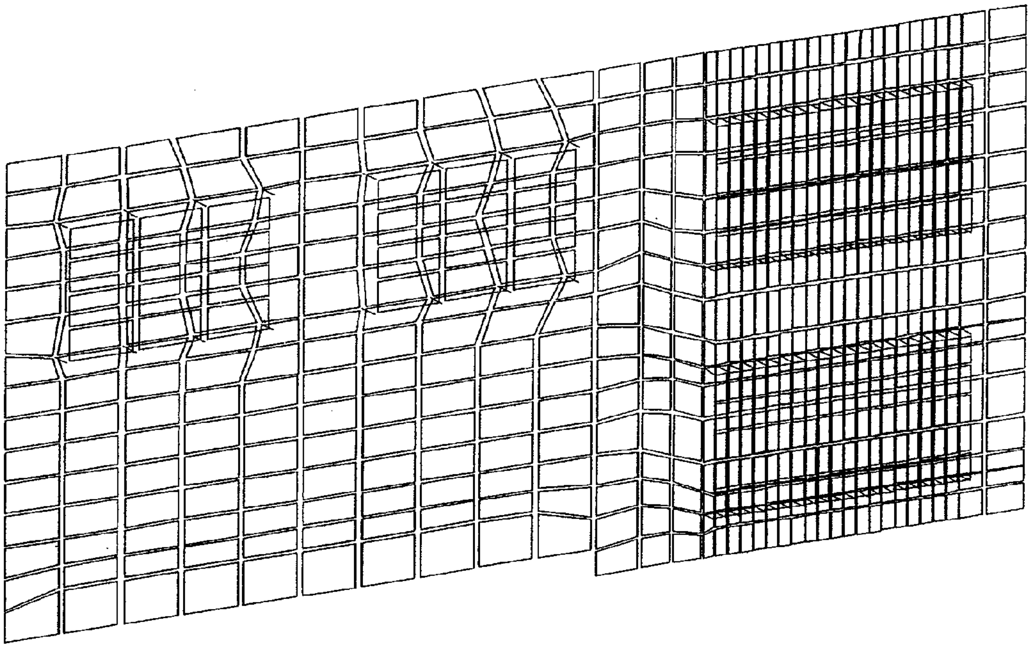

Figure 5. Finite Element Model of PWB

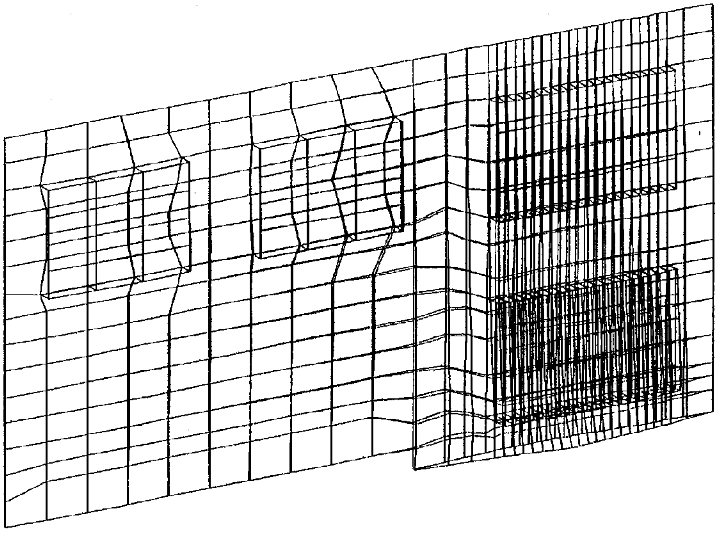

Figure 6. View Showing Warped Geometry

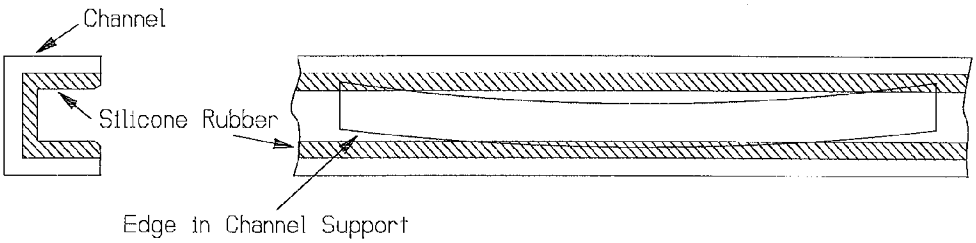

Figure 7. Channel Support - Edge in Channel with Compression Set

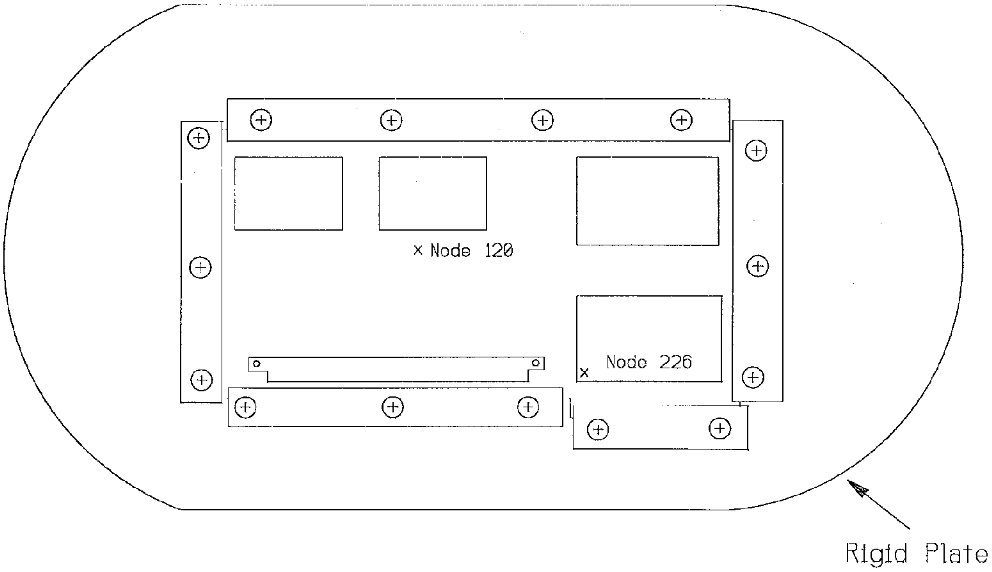

Figure 8. Chassis Level Test Set-Up

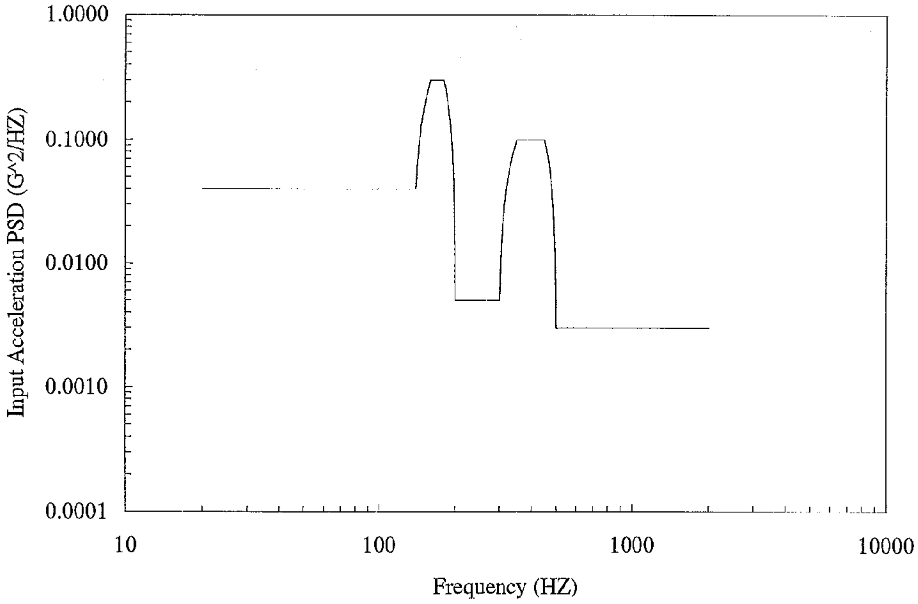

Figure 9. Input Acceleration PSD

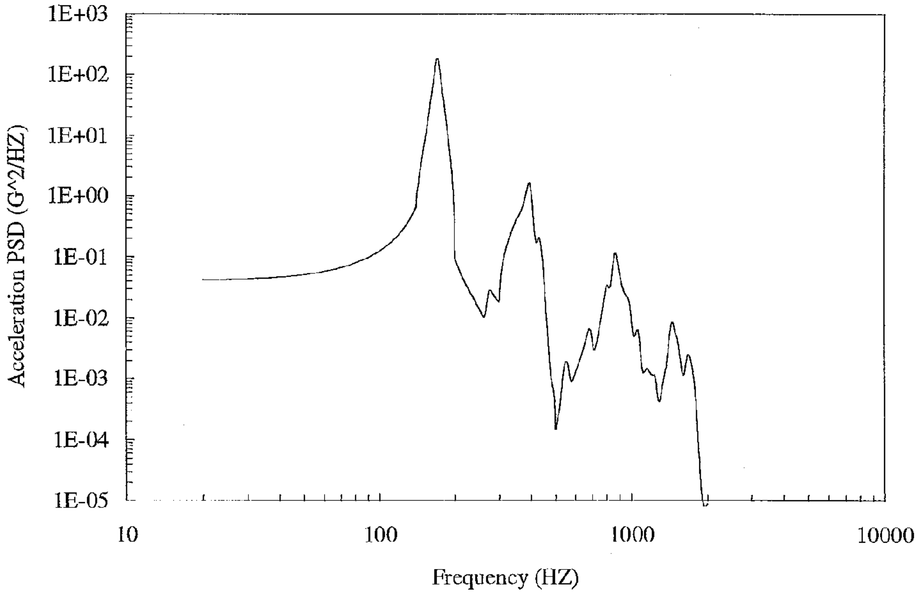

Figure 10. Acceleration PSD at the Center of PWB

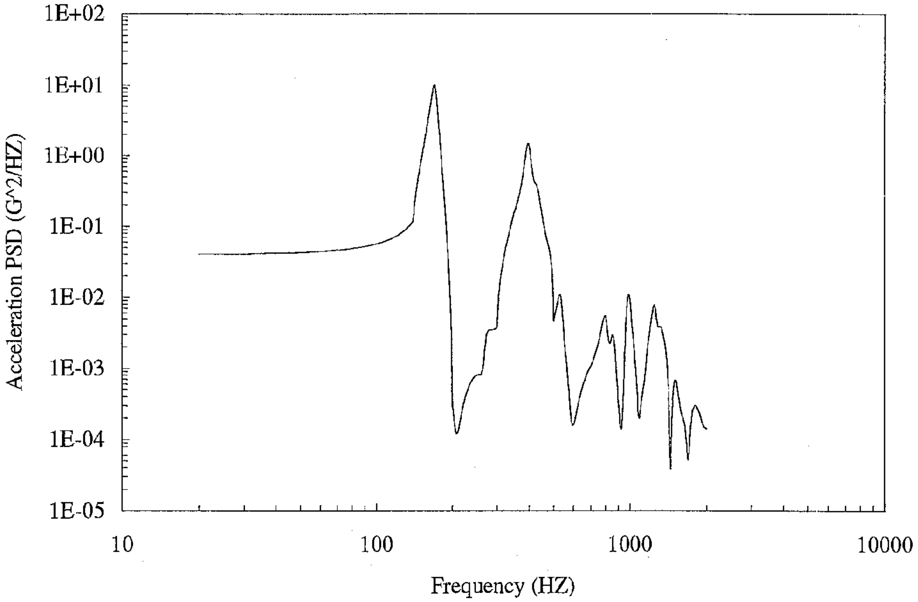

Figure 11. Acceleration PSD at Pin 1 of Hybrid # 4

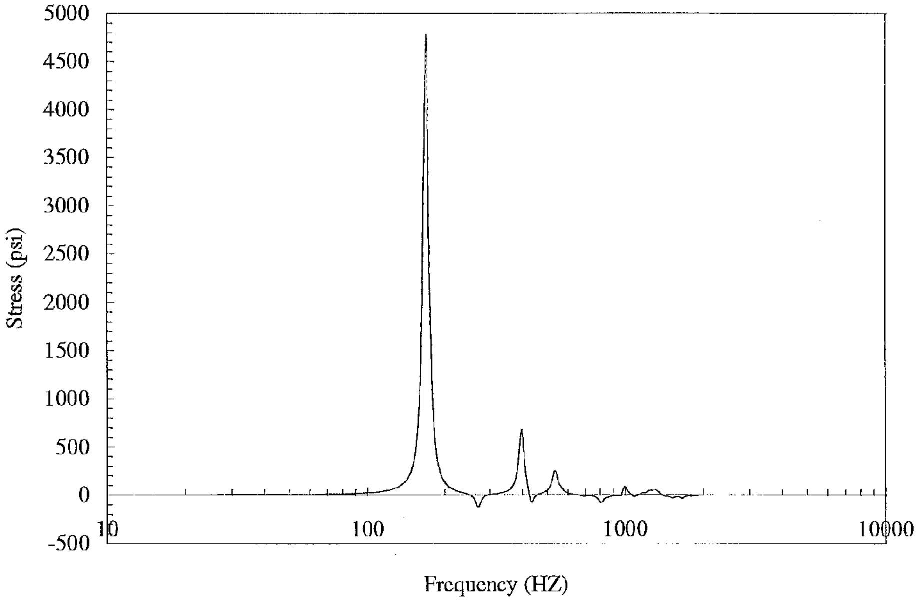

Figure 12. Stress Response of Pin # 1