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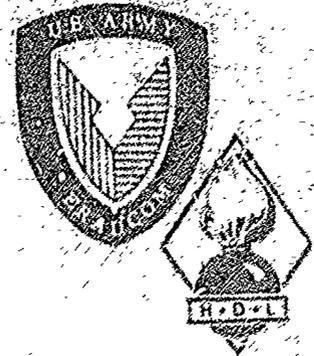
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Viscoelastic Polymer for Printed-Circuit-Board
Vibration Damping

by Mark R. Probst

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Harry Diamond Laboratories
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A viscoelastic polymer was selected as a possible means of vibration damping for electronic printed-circuit-board (PCB) assemblies in a surface-to-air guided-missile application. Thin layers of the self-adhesive polymer were bonded to dummy and real PCB assemblies, and accelerations were recorded at various PCB locations during sinusoidal vibration tests. For input levels of 1 and 2 g and logarithmic frequency sweeps from 10 to 2500 Hz,		

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→ peak resonant acceleration levels were reduced to 15 percent of the peak levels recorded under the same conditions with no damping layers added. ←

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1. INTRODUCTION

Printed-circuit-board (PCB) encapsulation (potting) is an effective means of protection from shock and vibrational environments, but the following problems are commonly associated with this technique.

- (a) High-temperature potting cure can damage components.
- (b) Internal stresses during and after curing can damage components.
- (c) Potting materials tend to be good thermal insulators and can prevent adequate component cooling.
- (d) PCB repair can be very difficult or impossible.

An effective alternative to potting is to pack small silicone rubber particles into a closed assembly containing those PCB assemblies for which protection is required.¹

Because of the problems associated with potting and a predetermined packaging concept which precluded the silicone rubber technique, an alternative method was required for PCB shock and vibration protection in a surface-to-air guided-missile environment.

2. VISCOELASTIC VIBRATION DAMPING

"Viscoelastic damping materials are helping to solve a number of special noise and vibration problems. Materials of this sort are being used on aircraft, saw blades, skis, and even skyscrapers."²

The particular viscoelastic polymer evaluated herein is made by the Industrial Specialties Division (ISD) of the 3M company. The damping system consists of a self-adhesive layer of polymer bonded to a reinforced-plastic constraining layer (fig. 1), and the polymer side is bonded directly to the structure requiring vibrational damping. The polymer is made up of randomly tangled chainlike molecules, and the intermolecular viscous friction during structural vibration dissipates some of the structure's vibrational energy.²

¹R. Richard Palmisano and Darrell W. Neily, *Particulate Silicon Rubber: An Effective, Removable Encapsulant for Electronic Packaging*, Harry Diamond Laboratories, HDL-TR-1762 (August 1976).

²*Polymer Damps Vibration and Noise by Converting Dynamic Energy to Heat*, Product Engineering (December 1977), pp 27-28.

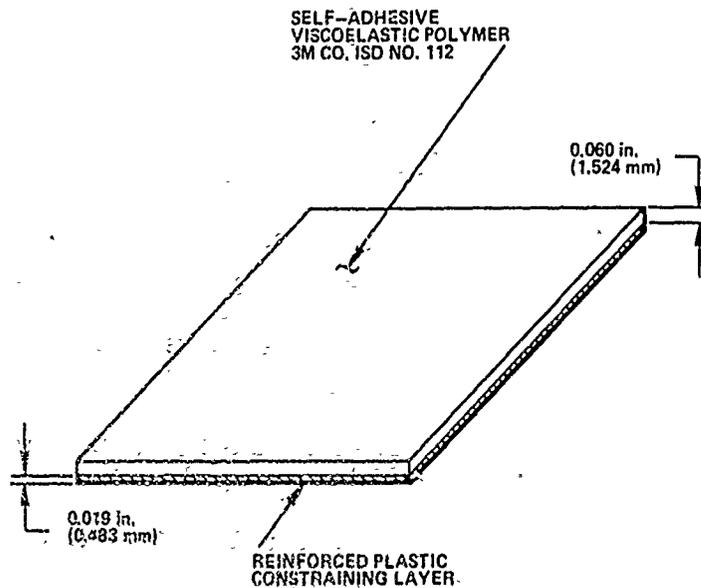


Figure 1. Viscoelastic damping system.

3. PCB APPLICATION OF VISCOELASTIC DAMPING

Since the solder-tip side of a high-component-density PCB assembly presents a nonuniform surface, unlike the application examples described in the Product Engineering article,² it was assumed that attaching the damping material to the PCB assembly would be difficult. A good mechanical bond is required to insure energy transfer from the vibrating PCB to the damping material, yet PCB reparability is a highly desirable feature which could be jeopardized by a bonding technique which would be otherwise acceptable.

The above factors, combined with an absence of experience with the viscoelastic material, led to the conclusion that a two-stage product evaluation would be the most economical approach. Stage one would consist of simple, easily repeatable quantitative measurements of the material's damping capability. If the damping capability proved adequate, stage two would consist of the design and evaluation of an acceptable method for attaching the damping system to a PCB assembly. An acceptable method would preferably possess all the following features:

- (a) efficient energy transmission from PCB to damping material,

²Polymer Damps Vibration and Noise by Converting Dynamic Energy to Heat, Product Engineering (December 1977), pp 27-28.

- (b) no introduction of circuit performance degradation,
- (c) elimination or minimization of the possibility of PCB damage during damping system attachment,
- (d) possibility of component replacement, and
- (e) small cost with respect to PCB.

Features (a) through (c) are absolute requirements, while failure to possess (d) and/or (e) would have to be considered in light of the overall system requirements. If, for example, a method possessed all features except (d), it might be possible to add this feature by increasing the cost. Such a trade-off could be evaluated by comparing the increased first-time assembly cost with the potential saving realized when a "throw-away" assembly is converted to a repairable item.

3.1 Stage One--Evaluation of Damping Capability

A simple model (fig. 2) consisting of 0.065-in.-thick (1.651-mm) epoxy-fiberglass laminate (NEMA Grade G-10) and uniformly distributed steel weights was used for initial evaluation. Board size and mounting configuration were based on the intended application, but no attempt was made to faithfully model any specific components or layout.

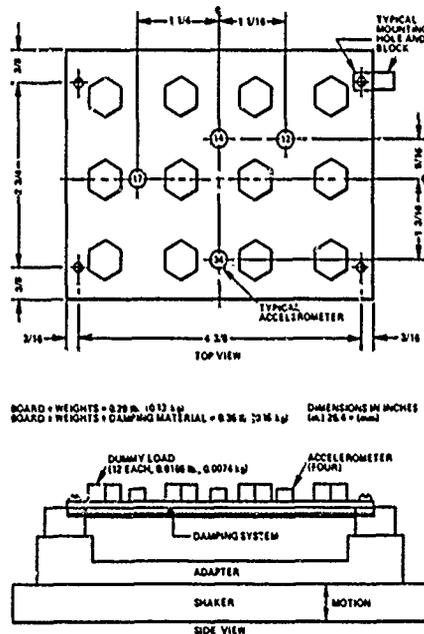


Figure 2. PCB model.

3M Company's ISD No. 112 is a self-adhesive viscoelastic polymer which peaks in damping capability in the temperature range of 60 to 100 F (15 to 38 C). It was supplied by 3M in a 0.060-in. (1.524-mm) layer bonded to a 0.019-in. (0.483-mm) reinforced plastic constraining layer. Attachment to the model PCB was accomplished by merely peeling off the protective paper cover and pressing the polymer layer against the smooth side of the board. Accelerometers were positioned as shown in figure 2.

Sinusoidal vibration tests were run using a 7.5-min logarithmic sweep from 10 to 2500 Hz. Four runs were made in which the variables were input excitation level (1 or 2 g) and vibration attenuation (damped or undamped). Table 1 shows the results of these runs, called tests 1 through 4. Higher-order harmonics were encountered, but peak acceleration levels were insignificant with respect to those encountered at the model's primary natural frequency. For tests 1 and 2 (1-g input), peak g values with damping averaged 13 percent of those without damping. For tests 3 and 4 (2-g input), peak values with damping averaged 16 percent of those without damping. Though the additional weight of the damping system alone would lower the model's natural frequency, the increased stiffness due to the damping material plus the constraining layer yielded a net 25-Hz increase in model natural frequency.

The above results clearly indicated that the viscoelastic damping material could greatly reduce acceleration amplification at system resonances, and thus stage one of the product evaluation was positively concluded.

3.2 Stage Two--Damping Layer Attachment

Although the 3M Company's application engineers had no direct experience with PCB vibration damping via viscoelastic polymers, they felt that the material was sufficiently compliant to allow the solder-tip side of a PCB to be pressed against it hard enough to allow adequate contact between the self-adhesive damping material and the flat portion of the PCB. This may be true if component density is not too high, but for the intended application, component density on some boards was very high (average of 28 leads/in.²). The force required to press the solder tips (0.060-in. maximum length) into the damping material could lead to board and component damage unless the board could be rigidly supported, but an economical support method for a PCB densely populated with discrete components could not be found.

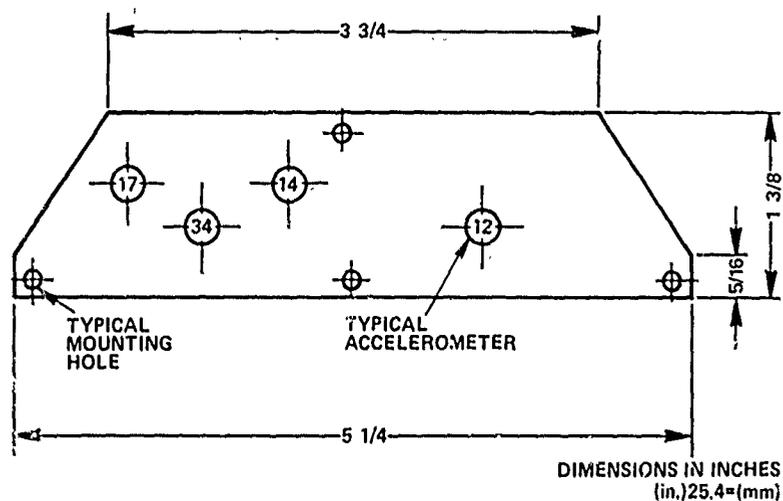
TABLE 1. SINUSOIDAL VIBRATION TEST DATA

Test No.	Input Level (g)	Damped ?	Accelerometer No. 12		Accelerometer No. 34		Accelerometer No. 14		Accelerometer No. 17	
			Peak g	Frequency (Hz)						
1	1	No	32	175	45	175	52	175	29	175
2	1	Yes	4.3	200	5.1	200	6.7	200	3.9	200
3	2	No	54	175	76	175	87	175	49	175
4	2	Yes	8.9	200	12	200	14	200	7.9	200
5	1	Yes	4.3	250	7.0	250	6.5	250	4.2	250
6	2	Yes	8.8	250	13.9	250	13.0	250	8.2	250
7	1	No	31.6	750	7.0	625	2.6	625	12.6	625
			5.4	1180	4.6	750	2.0	750	15.8	750
8	1	Yes	4.3	830	2.0	650	1.7	600	2.8	680
			2.6	1400	1.7	850	3.4	880	3.4	880
					2.8	1300	2.6	1050	2.6	1050
9	2	No	55.7	750	14.0	625	5.4	625	25.7	625
			13.6	1200	8.3	750	3.7	750	28.9	750
10	2	Yes	7.7	830	3.4	630	3.7	580	4.8	680
			4.6	1400	3.4	856	2.8	940	7.0	880
				5.0	1300	4.0	1150	5.3	1640	

The next method considered for damping layer attachment was to provide solder-tip clearance in the damping layer by drilling a 0.10-in. (2.54-mm) diameter hole at each solder-tip location. In a production situation where PCB's are drilled with numerically controlled equipment, the existing drill tape could be used to drill the clearance holes in the damping material. Before this method was pursued further, a test was run to determine the effect on damping capability which might result when a significant amount of the energy-dissipating material was removed. The same model used in tests 1 through 4 was used, but 25 percent of the damping system was removed by random drilling of 0.10-in. diameter holes. Table 1 shows test results for 1- and 2-g inputs as tests 5 and 6; the only significant difference from tests 2 and 4 is the increase in natural frequency which is due to weight decrease without significant change in stiffness.

The final tests included in this report were conducted on a functional PCB assembly (fig. 3). The PCB drill tape was used to drill 0.10-in. diameter solder-tip clearance holes in the damping system, and then the material was cut to match the PCB outline. Cutouts were included to allow rigid mounting against the four 0.25-in. (6.35-mm) diameter mounting standoffs. Polyurethane conformal coating had been applied to the PCB assembly, and the solder-tip side was cleaned with trichlorethane before the damping system was pressed in place. This PCB was much less crowded (13 leads/in.²) than the remaining boards in the system, but it was the only sample available for testing. Accelerometer locations are shown in figure 3; table 1 shows the test results as tests 7 through 10. For accelerometer location No. 12, peak accelerations with damping were only 14 percent of peaks without damping for both the 1- and 2-g inputs. Acceleration attenuation for other locations and for higher-order resonances was not as good on a percentage basis, but for all these cases, the peak levels with damping were no greater than 7.0 g and no greater than 3.5 times the input g level.

The machinability of the damping material was a minor problem for the above test--the material is extremely gummy and tended to build up on the drill. This minor trouble was magnified when damping layers were drilled for the more densely populated PCB assemblies, and it was necessary to use a backup material which would clean the drill after each hole. The resultant damping layers were unacceptable because small particles of the backup material were thrown outward around each hole and forced between the protective paper cover and the self-adhesive damping material. Various efforts to remove the embedded particles failed. When a wooden backup was used, the sawdust particles led to insufficient bonding between the PCB and damping system. When aluminum was used as a drilling backup, the conductive bits were a potential source of electrical shorts.



PCB ASSEMBLY + CONFORMAL COATING = 0.064 lb. (0.029 kg)
 PCB ASSEMBLY + CONFORMAL COATING + PERFORATED DAMPING MATERIAL
 = 0.086 lb. (0.039 kg)

Figure 3. Functional PCB assembly (top view).

For a production PCB application of the viscoelastic damping system, an acceptable attachment method must be devised. A possible solution which has not yet been tried would be to sandwich a spacer between the PCB and the damping material. This spacer would be 0.065-in. thick epoxy-fiberglass laminate with 0.10-in. diameter solder-tip clearance holes drilled via the PCB drill tape. A plain (undrilled) layer of damping material (constraining layer plus viscoelastic) could be attached to this board, and then this subassembly could be bonded to the solder-tip side of the PCB using polyurethane conformal coating. The self-adhesive damping system could be peeled off to permit PCB repair and then replaced after the repair.

Though this technique appears to add 0.065 in. to the total assembly thickness, it would be possible to pare down this increase or even decrease the previous thickness of 0.144 in. (0.65-in. PCB + 0.060-in. polymer + 0.019-in. plastic constraining layer). Since the PCB stiffness would be greatly increased by the 0.065-in. spacer, PCB thickness could be cut back to 0.035 or possibly 0.020 in. Since the 0.060-in. polymer thickness was originally intended to permit solder-tip imbedding, this dimension could be reduced significantly (tests showed no significant decrease in damping when 25 percent of the polymer was removed by drilling). The thickness of the constraining layer could be greatly reduced by substitution of metal for the reinforced plastic (the nonmetallic constraining layer would no longer be required since it would be insulated from the solder-tips by the undrilled damping polymer). In cases requiring electronic shielding between PCB

assemblies, the metal constraining layer would provide this function, and thus a further reduction in overall assembly thickness could be realized.

4. CONCLUSIONS AND RECOMMENDATIONS

Tests to date have shown that a properly designed and attached viscoelastic damping system can reduce acceleration amplification levels in printed-circuit-board assemblies by as much as 87 percent. Although reductions of this magnitude were not attained under all conditions of test, all tests showed significant improvement with the viscoelastic material applied.

The testing to date has only been performed on limited samples and under ambient temperature conditions. The test results are sufficiently promising to warrant further tests of the material. It is recommended that future evaluation of the following areas be made.

(1) Damping characteristics should be ascertained for the temperature range from -25 to +150 F (-31 to +71 C). (3M Company engineers indicated that a lamination of three separate polymers would be required to provide the most effective damping over this range, but suggested that the ISD No. 112 polymer might prove adequate if some degradation could be tolerated at the temperature extremes.)

(2) Chemical inertness should be determined to establish shelf life before and after application and to identify any tendency to decompose or initiate corrosion.

(3) The material's ability to resist moisture absorption should be determined.

(4) Electrical inertness regarding the dielectric strength, dielectric constant, resistivity, and dissipation factor of the material should be ascertained to assure absence of adverse effects on circuit operation.