

CCA Passive Vibration Damper

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Abstract

This paper summarizes the approach used to design and implement polyurethane elastomeric dampers between a Circuit Card Assembly (CCA) and a metal chassis. The dampers were added to reduce high CCA vibration levels experienced during random vibration testing. The paper addresses damper-level design, analysis, build and test issues, and electronics assembly-level analysis and testing results.

Key words: CCA, damper, vibration, passive damping, elastomer, FEA

Background

The subject of this paper is a custom-designed CCA vibration damper that has been in service for over 20 years, but recently required redesign due to acceptance pull testing failures. The problem was initiated by a change in the polyurethane elastomeric potting material used in the design, but the redesign and failure investigation process revealed several other issues.

Vibration dampers were originally added to the CCA/chassis subassembly because of high acceleration responses measured during random vibration testing used to simulate the launch environment. The dampers were added based on available space in the CCA/chassis subassembly, one near the center of the CCA and a second one closer to one end. The dampers met the goal of reduced acceleration response.

Damper Design

Figure 1 shows the original damper design, which consists of a polyurethane resin potting material molded between two stamped 304 stainless steel end plates. In the application discussed herein, two dampers are assembled between a CCA and a metal chassis whose primary means of attachment is six screws around their periphery (Figure 10). One side of the damper is screwed to the CCA and the other side is screwed to the metal chassis. The two dampers are located along the centerline of the assembly in order to reduce the relatively large CCA centerline displacements that would otherwise occur during vibration.

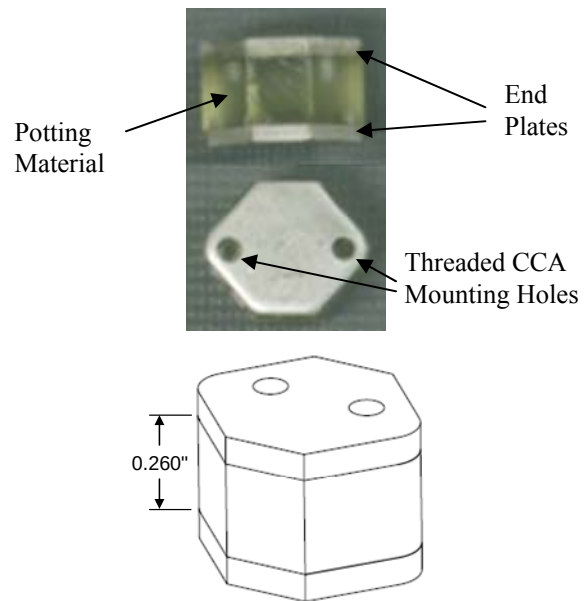


Figure 1. Original CCA Damper Design

The original damper design used Cytec CONATHANE[®] EN-2 as the potting material. EN-2 is an unfilled, two-part resin/hardener that was selected because it has high strength and low stiffness, can be molded and cured at room temperature, has low outgassing properties, and performs well in high and low temperatures. When EN-2 was discontinued due to mercury content, EN-13, the non-mercury version of EN-2, was selected as the replacement based on the belief that it

had similar properties; however, subsequent axial pull testing (35 ± 2 lb requirement, perpendicular to the plane of the end plates) demonstrated that EN-13 did not have the requisite strength, necessitating damper redesign.

In the original design, the end plates were flat and thin, which permitted easier and cheaper manufacture via stamping. Because the EN-13 axial pull test failures were due to adhesive failure (peeling) at the end plate/potting material interface, flanges, or "hooks," were added to the end plates (Figure 2). However, based on finite element analysis (FEA) and axial pull test results, it was discovered that the hooks led not only to increased stress in the potting material but also to increased axial stiffness of the damper. In addition, installed dampers were failing prior to vibration testing.

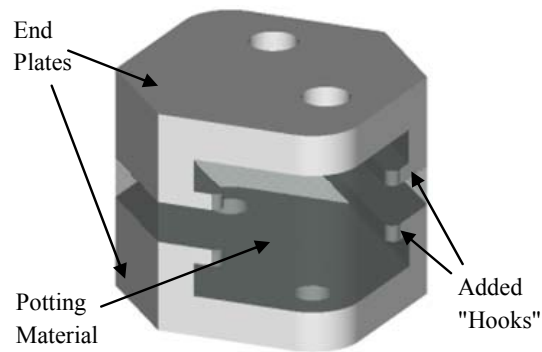


Figure 2. First Attempt at Damper Redesign

As a result of unacceptable performance, the hooked end plate redesign was abandoned, the flat end plate design was restored, and the failure investigation was expanded to include the damper build and installation processes.

The damper build process investigation revealed detrimental misalignments caused by the molding fixture, which, when coupled with slight CCA and metal chassis mounting offsets and increased damper stiffness, led to continued damper failures.

Consequently, the end plates were offset slightly in the molding tool to account for mounting hole misalignment (Figure 3) and an attempt was made to provide better end plate rotational control in the molding tool. The resulting damper redesign was deemed acceptable for use in product.

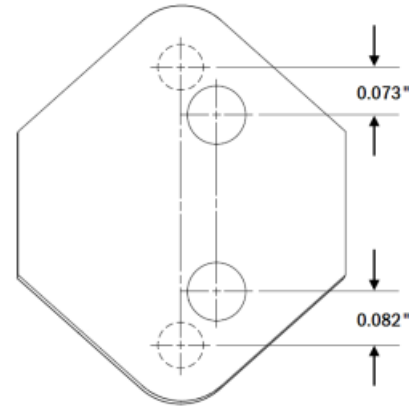


Figure 3. Redesign Configuration with Offset Mounting Holes

A second damper redesign was motivated by a CCA redesign that resulted in increased CCA weight, requiring a stiffer damper. To accomplish this, a number of different CONATHANE[®] polyurethane elastomers were investigated: EN-13, TU-8070, EN-21 and EN-4/EN-9 (part A/part B). All are liquid, two-component potting compounds. As seen in Table 1, TU-8070, EN-21, and EN-4/EN-9 are all stronger than EN-13; per pull testing, they are also stiffer than EN-13. However, EN-13 had the advantage because mixing and use procedures had already been developed. In addition, because EN-13 was the only candidate with a 1:1 mix ratio (by volume), it could be accurately dispensed using a standard 1:1 dual syringe.

Table 1. CONATHANE[®] Potting Material Typical Cured Mechanical Properties

Mechanical Property	EN-13	EN-2	TU-8070	EN-21	EN-4/EN-9
Tensile Strength, psi	600	900	1500	2000	2000
Tear Strength, pli	37	130	275	119	275
Hardness, Shore A	65	75	40	80	90
Elongation, %	110	130	745	155	450

Therefore, instead of changing the potting material, the potting material thickness was decreased to increase axial stiffness. Because the weight of the CCA nearly doubled, the thickness of the potting material was decreased 50% (Figure 4). To maintain the same overall damper height, the thickness of the

stamped stainless steel end plates was increased, requiring that they be machined.

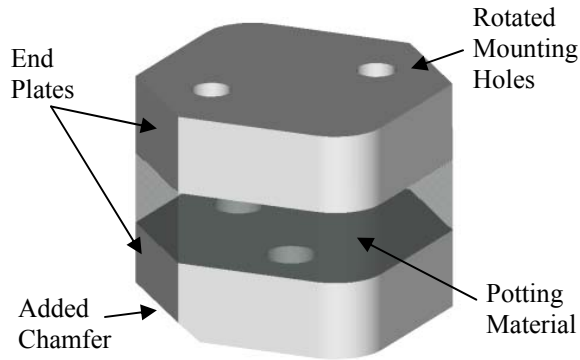


Figure 4. Final Design Configuration for Heavier CCA

In addition, to allow for improved layout of various CCA components and to avoid an interference with the metal chassis, the CCA mounting holes in the top end plate were rotated 90° and a chamfer was added to the edge of the bottom end plate.

Table 2 provides a summary of the various damper designs. In this paper, the various damper designs are identified per the design titles in this table.

Table 2. CCA Damper Design Summary

Design	Potting Material	End Plates	Axial Stiffness lb/in	Status
Original	EN-2	Flat, thin	~625	Discontinued
Initial Redesign Attempt	EN-13	Hooked	~1230	Not used
1st Redesign	EN-13	Flat, thin	~625	Used with original CCAs
2nd Redesign	EN-13	Flat, thick	~1208	Used with heavier CCAs

Damper Analysis

FEA of the various damper designs was conducted in parallel with redesign activities. Figure 5 shows the I-DEAS finite element model (FEM) of the original damper design. Because linear, elastic analysis was assumed, the model was used to provide a relative comparison of potting material peak stress and damper stiffness for the original design and the different redesigns

considered. Not all material properties necessary for linear analysis (let alone hyperelastic analysis) were available from the manufacturer, so the model was tuned (i.e., the room-temperature elastic modulus of the potting material was adjusted to 700 psi) such that the hooked end plate/EN-13 redesign model, Figure 6, duplicated the axial stiffness of the damper derived from axial force-deflection test data for the same configuration. The force-deflection test data was linear up to about 20 lbs, suggesting that the linear FEM of the initial redesign attempt should be adequate for loads up to about 20 lbs.

Initially, FEA was used to compare the axial strength of the flat end plate/EN-2 original design with the hooked end plate/EN-13 initial redesign. The analysis found that for the same axial load, the initial redesign had a 20% higher peak stress in the potting material coupled with a lower strength potting material. Assuming that linear FEA stress results were accurate, the model of the original damper design confirmed that a 35 ± 2 lb axial load (the pull test requirement) was acceptable (which had been known for years), but that the same load was marginal for the initial redesign. Therefore, in conjunction with pull testing that demonstrated linear force-deflection results up to about 20 lbs, the axial force requirement was decreased to 20 ± 2 lbs. This change increased damper yield and was subsequently proven to be acceptable by random vibration analysis and test results at the electronics assembly level.

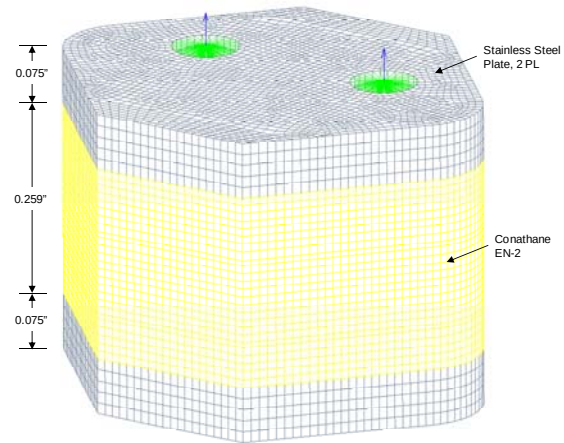


Figure 5. FEM of Original Damper Design

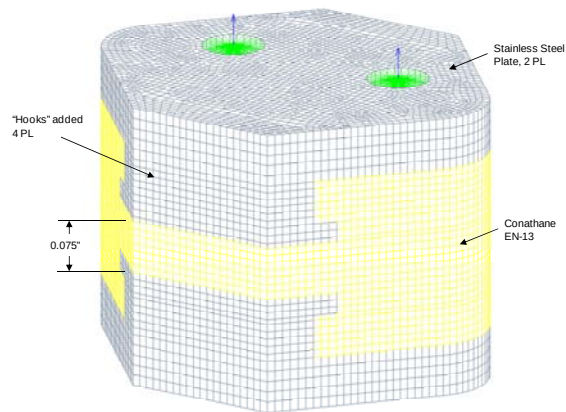


Figure 6. FEM of First Attempt at Damper Redesign

The analysis also found that the initial damper redesign attempt had twice the axial stiffness of the original design, which was not consistent with the objective of matching the original stiffness. The increased stiffness was due to the intrusion of the hooks into the potting material. None of the initial redesign dampers were used in product.

FEA was also used to verify that the damper redesign for the heavier CCA application had the expected axial stiffness and acceptable stresses.

Damper Build

The CCA dampers are assembled in-house, using custom molds. The heritage process had been used successfully for over 20 years, but was reevaluated during the course of the axial pull test failure investigation. As described earlier, the investigation uncovered misalignment between the top and bottom end plates, which, although not a problem for the original damper design, was sufficient to overstress the initial redesign of the damper because of the lower strength potting material and stiffer damper design.

Figure 7 shows the heritage mold tool and the misalignment that could result. Because of the misalignment, the mold tool was redesigned. The new tool, shown in Figure 8, has positioning pins to locate the mold halves and shoulder screws to control the relative position of the end plates, minimizing the potential rotation of the end plates.

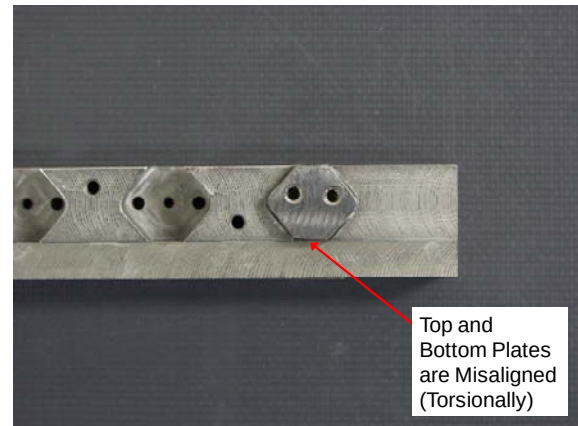


Figure 7. Heritage Damper Molding Tool

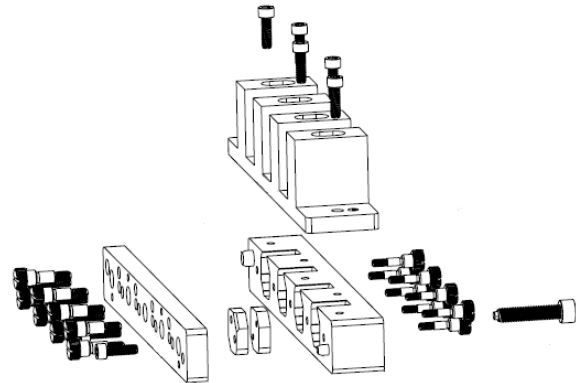


Figure 8. Improved Damper Molding Tool

Both the heritage and redesigned damper mold tools use end plate mounting screws that simulate the depth of the hardware that is used to mount the damper to the CCA and metal chassis. This ensures that the potting material is molded around the required screw threads to the appropriate depth so that the actual hardware does not thread into un-tapped potting material.

In addition to redesigning the mold tool, the process used to ensure good adhesion of EN-13 to the end plates was reviewed. This process included roughening, cleaning, and priming the appropriate end plate surfaces with CONAP[®] AD-1146 to increase the adhesion of the potting material.

Another issue with the molding process was voids in the cured potting material (Figure 9). This issue was resolved by improving the EN-13 processing methods, including: 1) using a dual syringe with a static mixing tube to dispense the two-part resin/hardener (to minimize the introduction of air relative to a weigh/pour/stir manual mixing method); and, 2) de-gassing for 15 minutes followed by 60°C cure for 3 hours (per manufacturer's recommendation).

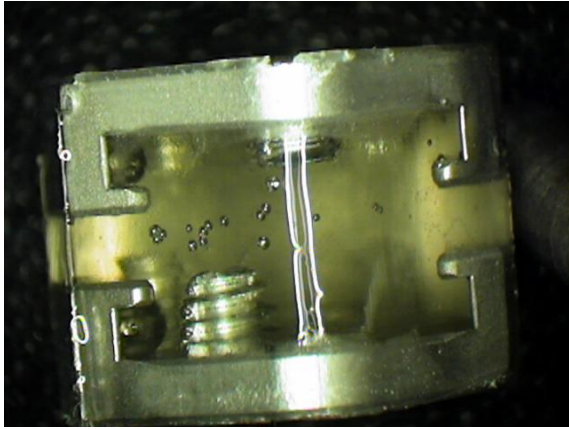


Figure 9. Initial Damper Redesign with Voids in the Potting Material

Damper Test

Table 3 summarizes average axial stiffness, in increasing order, and minimum allowable axial load based on data from three damper axial pull tests per elastomer type. All tested dampers had flat end plates; one set of dampers had thick end plates. This information was needed for electronics assembly FEA.

Table 3. Damper Axial Stiffness and Allowable Load with Flat End Plates

Potting Material	Axial Stiffness lb/in	Allowable Axial Load lb
EN-13	625	29
EN-21	750	53
EN-13, 0.140" thick elastomer	1208	35
TU-8070	1288	47
EN-4/EN-9	2429	>71

Axial stiffness was based on the linear portion of the force-deflection curve. Allowable axial load was based on the minimum failure load (from three tests) divided by a factor of safety of 1.4. EN-4/EN-9 did not fail at the 100 lb tensile tester load cell limit. All of the potting materials met the 20 ± 2 lb pull test requirement.

CCA/Chassis Subassembly Build

Figure 10 depicts the CCA/chassis subassembly with two dampers (not visible) assembled in between. Figure 11 shows the locations of the two dampers on the metal chassis. The damper locations were established during retrofit more than 20 years ago and are likely not ideally placed. Due to damper investigation limitations, there was no

attempt to change the CCA/chassis subassembly design to accommodate better damper placement.

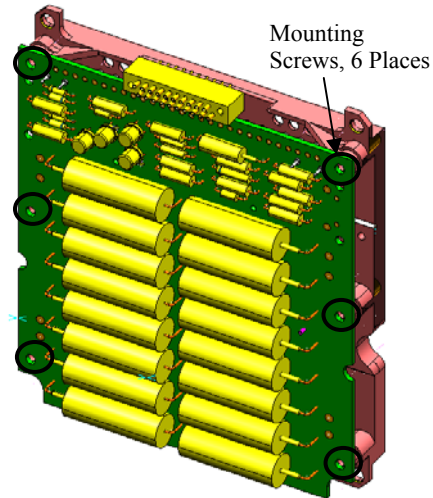


Figure 10. CCA/Chassis Subassembly

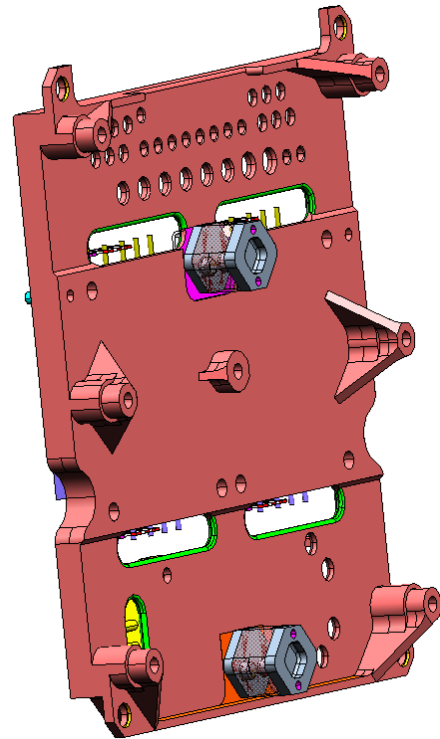


Figure 11. Location of Dampers

As previously mentioned, subsequent to the initial damper redesign attempt, dampers continued to fail after installation in the CCA/chassis subassembly, leading to the discovery that damper mounting holes were not aligned adequately with corresponding CCA through holes (Figure 12). Two approaches were employed to resolve this problem:

1) offset the damper end plate mounting holes, as previously described (1st redesign); and, 2) increase the diameter of the CCA through holes (2nd redesign).

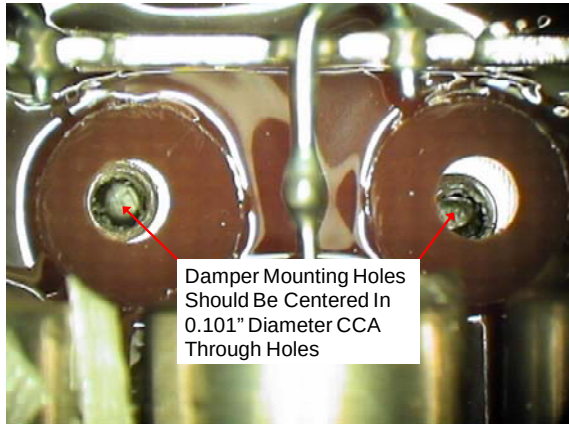


Figure 12. Damper Misalignment (Looking Through CCA)

Electronics Assembly Analysis

FEA of the entire electronics assembly was performed. Figure 13 shows the FEM of the electronics assembly with the cover removed. The electronics assembly includes four CCA/chassis subassemblies; thus, each electronics assembly contains eight CCA dampers. The electronics assembly FEM, which was tuned to match available vibration test data (natural frequency and gain), was used to determine the best damper design based on a conservative interpretation of Steinberg's allowable 3σ deflection criteria [1]. The FEM, which was subjected to qualification random vibration levels, also provided damper axial forces for comparison with allowable axial force.

In addition to a no-damper case—which verified the need for dampers—six damper candidate cases were analyzed:

- COTS (commercial off-the-shelf) isolator
- EN-13
- EN-21
- EN-13 with thicker flat end plates
- TU-8070
- EN-4/EN-9

The choice of COTS isolator candidates was severely limited by the space available in the CCA/chassis subassembly. The COTS isolator considered had limited axial strength. CCA/chassis subassembly redesign to accommodate better COTS isolator candidates was not a viable option.

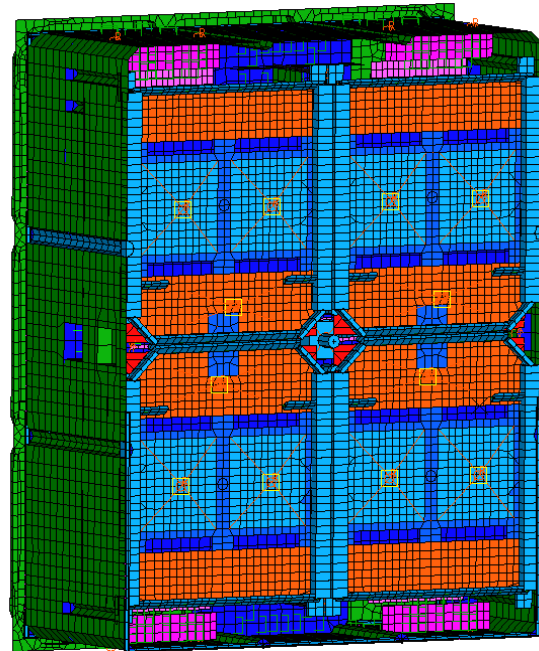


Figure 13. Electronics Assembly FEM (None of the Eight CCA Dampers is Visible)

Electronics assembly-level FEA was done using MSC.Nastran. Direct frequency response analysis was employed. The FEM included structural damping based on vibration test results with no CCA dampers installed.

Each damper was modeled as a spring element in parallel with a viscous damper element. The 6 degree of freedom (DOF) stiffnesses of the COTS isolator were based on axial and lateral stiffnesses from the data sheet and beam formula estimates for the other DOF. The axial stiffness of each in-house damper was based on axial test data. All other damper stiffnesses were scaled using stiffness ratios obtained from the detailed FEM of the original damper design (Figure 5).

The damping coefficient, c , was estimated for the three translational DOF using Equation 1.

$$c = \eta(k \cdot m)^{0.5} \quad (1)$$

where

η = loss factor

k = damper static stiffness

m = damped mass

η , which is $\sim 1/\text{gain}$ at resonance, was 0.23 for the COTS isolator (from supplier e-mail communication; data sheet suggests 0.2) and estimated to be 0.2 for the in-house dampers.

In the axial direction, k was 31 lb/in for the COTS isolator (based on a data sheet dynamic stiffness of 32 lb/in and the formula $k = k_d/(1+\eta^2)^{0.5}$). Table 3 provides in-house damper axial stiffnesses.

Damped weight was estimated to be 1 lb (for the redesigned, heavier CCA), leading to $m = 1/386.1$ lbf-sec²/in.

Table 4 lists electronics assembly FEM predictions of the 3σ deflections at the center of the CCA for comparison with a 0.009" Steinberg allowable. Table 4 deflections are relative to the nearest mounting points. The corresponding CCA deflections at the other (end) damper location were lower.

Table 4. CCA Deflection Results from FEA

Case	3σ Deflection in.	Pass/Fail
No dampers	0.0113	Fail
COTS isolator	0.0083	Pass
EN-13	0.0051	Pass
EN-21	0.0048	Pass
EN-13, 0.140" thick elastomer	0.0044	Pass
TU-8070	0.0044	Pass
EN-4/EN-9	0.0039	Pass

The electronics assembly FEM also provided the center damper 3σ axial forces listed in Table 5. Only the COTS isolator had excessive axial forces. The corresponding axial forces at the other (end) damper location were lower.

Table 5. Damper Axial Force Results from FEA

Case	3σ Force lb	Allowable lb	Acceptable?
COTS isolator	1.2	0.2	No
EN-13	4.3	29	Yes
EN-21	4.8	53	Yes
EN-13, 0.140" thick elastomer	6.2	35	Yes
TU-8070	6.4	47	Yes
EN-4/EN-9	8.7	>71	Yes

Table 5 axial forces are the sum of the magnitudes of the spring and damper forces, i.e., to be conservative, spring and damper forces were assumed to be in phase.

The axial force allowable does not include the effect of assembly misalignment due to part tolerances. This effect was investigated for the EN-13 damper and estimated to be 5 lb (worst case).

Table 5 results, combined with estimated axial loads due to assembly misalignment, confirmed that the new 20 ± 2 lb axial pull test requirement for

the in-house damper design was appropriate (and that the previous 35 ± 2 lb requirement was excessive).

Lateral forces and moments were not of concern because six screws around the periphery of the CCA/chassis subassembly provide the primary load path for lateral loads and ensure that rotations are small. The only loading direction of concern was perpendicular to the plane of the CCA (i.e., the damper axial direction).

All candidates, except the COTS isolator, were deemed to be acceptable. The two EN-13 alternatives were judged to be the best candidates because, in addition to meeting all requirements, they presented the least risk in terms of process changes. The stiffer EN-13 candidate was selected for use in CCA/chassis subassemblies with heavier CCAs.

Electronics Assembly Test

Assembly level environmental testing included sine and random vibration and thermal cycling; however, the focus of this paper is on random vibration. Figures 14 and 15 show the instrumented CCA/chassis subassembly and electronics assembly vibration test set-up, respectively.

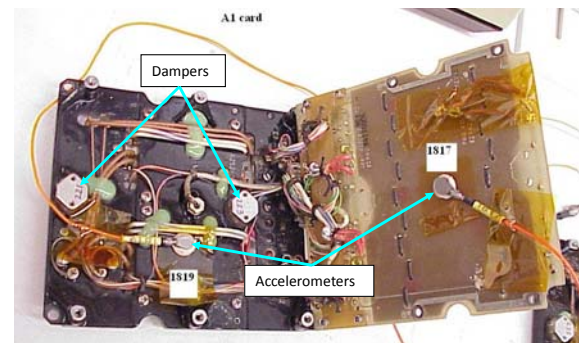


Figure 14. CCA/Chassis Subassembly Instrumented for Vibration Testing

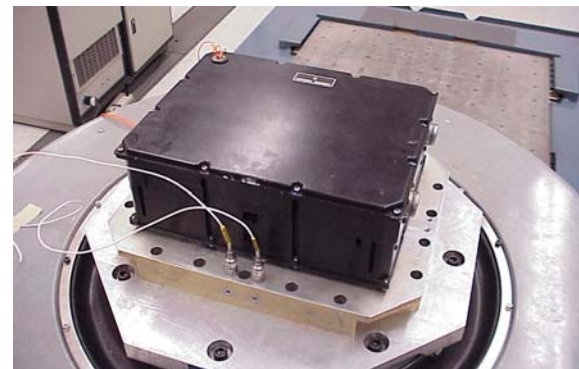


Figure 15. Electronics Assembly Mounted on Shaker

The vibration testing that was conducted had two objectives: 1) demonstrate the equivalency of the new dampers with flat end plates and EN-13 to the original dampers with flat end plates and EN-2 in terms of damping characteristics; and, 2) determine the relative damping characteristics of the final damper design, with and without cracks in the potting material.

CCA accelerometer data indicated that dampers (with and without cracks) increased CCA natural frequency from 320-350 Hz to 600-680 Hz and decreased gain from 15-20 to 9-10.

Chassis accelerometer data indicated that dampers (with and without cracks) decreased chassis natural frequency from 810-840 Hz to 590-670 Hz and decreased gain from 27-35 to 4-6. The natural frequency went down because the dampers coupled the centerline of the CCA to the chassis.

The vibration testing concluded that: 1) the final damper design provided the same level of damping as the original damper design; and, 2) the effective damping provided by cracked dampers is essentially the same as that achieved by dampers without cracks. Based on this testing, cracks in the dampers are allowable as long as they are not completely severing the damper potting material in half (such a configuration was not tested, hence no conclusion can be made regarding the acceptability of this case).

In practice, the dampers are only needed during launch, and serve no purpose during on-orbit operation.

Summary

The root causes of damper failure during the initial redesign of the CCA damper were:

- Damper end plate misalignment (top end plate relative to bottom end plate) in the mold tool
- CCA mounting hole misalignment (CCA relative to metal chassis)
- Weaker potting material (CONATHANE[®] EN-13 relative to EN-2)
- Higher stress damper design (hooked end plate design relative to original flat end plate design)

The corresponding corrective actions were:

- Redesign the mold tool to minimize damper end plate misalignment
- Offset the damper end plate mounting holes (alternative: increase the damper mounting hole diameters on the CCA)
- No change required to the potting material. Stronger potting materials were investigated, but there were significant advantages to staying with EN-13 because processes and procedures had already been developed.

- Return to the flat end plate design

Conclusions and Lessons Learned

The passive vibration damper approach used was effective at reducing CCA deflections to acceptable levels—even when the potting material was cracked.

Since CONATHANE[®] EN-13 is actually a lower strength replacement for EN-2, adequate provisions for the lower strength must be made. In the application discussed herein, those provisions ultimately consisted of understanding and reducing misalignment induced loads, rather than using higher strength alternatives. Success was preceded by an unsuccessful initial attempt at redesign—underscoring the importance of aggressive follow-up.

This investigation also highlighted the benefits of using both analysis and test effectively and correlating the two when possible.

References

1. Dave S. Steinberg, "Vibration Analysis for Electronic Equipment", John Wiley & Sons, second edition, New York, Chapter 8, p. 234, 1988.

Acknowledgements

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