A Comparison in Time to Failure

H&H ENVIRONMENTAL SYSTEMS, INC.

EXPERIMENTATION AT TEAM CORPORATION USING SINGLE AND MULTIPLE-AXIS VIBRATION

A Comparison in Time to Failure | Chris Peterson
The Test Hypothesis

The hypothesis for this test was that shaking on X, Y, and Z at the same time would have a different failure rate – presumably shorter – than anything calculated by the results of using the times to failures of the single axes.

To make the results more traceable only one failure mechanism was looked at; the reaction of the LED. That does not by any means presume that an LED failure would be the only failure found. Other types would be expected. However, if the test was stopped as soon as any failure (or weakness) at all was found then all it would really show would be the likely first failure on each single axis. The idea was traceability on one particular failure mechanism.

The Test Team

The design of experiment was done by Chris Peterson, representing H&H Environmental Systems, Inc., who oversaw all testing. Joel Hoksbergen did the majority of the fixturing work and took care of the Tensor while Chon Mech ran the software. (Each of the two gentlemen helped in the lab with the test set up and making sure the equipment was running smoothly.)

Single Axis vs. Multi-Axis vibration

Most test labs that run vibration have single axis shakers. In some cases they can be rotated so that a Z-axis shaker can change directions to be an X- or Y-axis shaker. Often this means a new fixture needs to be designed.

Combining shakers without a full understanding of what you are doing can lead to destroying the shakers. On a piece of equipment like the Tensor the same fixture can be used; a number of actuators are put into play. Therefore, when doing a test on an item that needs to be shaken in three exclusive orthogonal axes you can go right from one test to the next without ever moving the test item. You also have the choice of combining axes.

The Test Items

12 clocks were purchased from Amazon.com by H&H Environmental Systems and shipped in advance to Team. The name of the clock is “Moodicare” and the description on the box is “glowing LED color change digital alarm clock”. According to the manufacturer it was designed to soothe and relieve the pressure and stress brought about by living in a fast-paced society. To do that it goes through a cycle of seven different colors based on studies showing that light and color change can have a soothing effect. Please note that the clocks
were not purposely built to be able to withstand this type of testing.

Besides showing the time the clock fact also displays a symbol showing whether the alarm is on or off, the date, month and day, and the temperature (user selectable between F and C). It comes with two AG13 watch style batteries for powering the clock. The user must add four AAA batteries to power the LED. (New AAA batteries were used for each test.)

The weight of the unit with all batteries loaded is 139 grams (4.9 oz). The external dimensions are 79 x 79 x 78 mm (3.1” x 3.1” x 3.0”).

One item was used for comparison purposes only (a control unit) so that it would be easier to see if there were any changes to the units under test. It can be difficult to recognize faded numbers on an LCD unless two units are compared.

One unit was pulled apart so that the components could be identified, and was then later tested that way. It was decided to test a second unit that way, also.

Each test unit each got a piece of masking tape with a hand written number for tracking which test they went through. They were numbered 1 through 11 and C for the control unit.

The Choice of Test Items

While a digital alarm clock that changes colors to “improve mood” would not typically be carried in a military vehicle there were several reasons for using this as a test item.

1. Easily available
2. Non-proprietary
3. Inexpensive
4. A number of failure modes to look for:
   a. The clock can be measured against other time keeping equipment to see if the timer slips
   b. The LCD could blink, be partially visible, or go completely blank
   c. The LED could flicker, lock into one color, blink on only once in a while, or completely stop
   d. There could be structural damage including cracks, flaking, wires loosening, etc.
5. Easy to fixture (a cube)
If defense hardware would have been used then there would be much less of a possibility of sharing results. Many of the components are similar to what would be seen in the field; an LED, an LCD, a circuit board, wiring, etc. Therefore the general findings should be applicable to similarly crafted items.

That being said, it is important to note that the test findings are for this particular unit. If something like a vehicle radio or an aircraft radar detection system would have been tested the times to failure and failure mechanisms would be different. However, I believe that the same basic findings would hold true.

The Test Facility (Shaker)

A Team Tensor 18kN was used. The Tensor is a “fully contained multi-axis vibration test system capable of precise control of all six degrees of freedom through a 5 kHz bandwidth. The system can reproduce real world vibration environments by simultaneously exiting all three linear translations as well as all three rotations”. The goal is replication of real-world vibration environments in all 6 DoF.

This photo is the side view of the Tensor through the control room window. The computer monitor seen in the bottom right hand corner was from the unit controlling the shaker. The large cylinders on the side are the Y actuators, and on the right hand side you can see one of the X actuators. The clock is mounted in the center of the table for the test.

The Tensor couples electrodynamic shakers to the moving element with hydrostatic bearings. It uses dynamic control of all six degrees of freedom to precisely reproduce the desired response.
In this photo you can see two of the X actuators, the four Y actuators on the sides, and the front two of the Z actuators on the bottom and the red panel behind it is the power unit. The small blue plates attached to three sides of the table have target markings, and a laser pointer aimed at them allows for centering of the table before the testing begins.

The Tensor unit has 12 single axis shakers, 4 in each of the X, Y and Z axes. For X and Y the shakers are paired directly opposite of each other. The shaker is capable of vibration in the following axes:

- X – longitudinal
- Y – transverse
- Z – vertical

Roll is the rotation about X controlled by Z

Pitch is rotation about Y controlled by Z
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Yaw is rotation about Z controlled by X and Y

Even controlling to a single axis on this unit is considered to be 6DoF because the other axes are being controlled to a very small level. (The shakers in the other axes are minimizing cross-axis motion.)

The Vibration Fixture

Fixturing was kept lightweight and simple. A piece of UHMW (Ultra High Molecular Weight) plastic was used as a cross bar held in place by two threaded rods with nuts. These were screwed down into table inserts next to the each test item.

During the first test the clock moved because the nuts had come loose. A different configuration with the nuts was used and no further slippage was found.

This photo shows how the fixture was modified to hold both a full assembly (clock) and a sub-assembly (base unit) at the same time for the comparative testing. A piece of the UHMW plastic was placed on the table itself with a metal plate that would hold down the edge of the base so that it would not wiggle free during the testing. While it was firmly in place no wear was seen on the base after testing which proves that it was not torque down too tightly. While the metal piece comes very close to the components, it actually only touches the base.

Note that the response accelerometer is mounted on the fixture directly over the clock. It was not possible to affix it directly to the clock itself. The LED on the base was checked during the testing to verify that it never touched the threaded rod which would have skewed the test results.

Sensors

The accelerometers were from PCB. The calibration is good through next February. Four Wilcoxon Research model number 993A tri-axial accelerometers for control were used for control, one near each corner of the table. A PCB single axis accelerometer was
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mounted in the Z axis on the fixture directly above the test item and a second PCB was mounted on the table nearby. We named the sensors “response” and “reference”. The control was from the four corner accelerometers so was done by input. “Response” was only to get a general idea of what the test item was seeing and “reference” was to get the measurement of the table right next to the item.

Software

The software was written by Data Physics. It is called SignalStar Matrix, and the hardware for data acquisition and control is Abacus. 26 channels were used; 12 input for the tri-axial accelerometers, 12 output which are teed from the drives to both the amplifiers and the Abacus units, 1 input channel for the “response” accelerometer and 1 input channel for the “reference” accel. The operating system was Windows Vista. The data acquisition was at 0.625 Hz. All six axes and the rotational were controlled even if only one axis was excited.

15 graphs show data at the same time and any of them can be opened (as one has here) to get a closer look at the data. The original profile is shown as well as the data from all of the accelerometers.
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Test Lab Conditions

The lab was not temperature conditioned. The weather was nice and the outer door was sometimes open but it seemed to have no effect on the test. Temperatures ranged from approximately 71° to 80° F. No humidity reading was taken.

Before each test was started the table was leveled. Whether or not is was level was indicated by whether the lasers were shining into the targets.

A pre-test was run at various levels. For the single axis tests and tri-axial without rotation it was -12 dB for 1 minute, -9 dB for 30 seconds, -6 dB for 30 seconds, then -3 dB for 30 seconds. For the tri-axial tests with rotation it was -12 dB for 5 minutes, -9 dB for 2.5 minutes, -6 dB for 30 seconds and -3 dB for 30 seconds.

Limitations

The main limitation was time. I had two and a half days to complete as many tests as possible so I needed to put a two and one half hour cap on each test. I would have preferred to have had the time to test to complete failure. Therefore, the first item to show signs of wear became what was used as the main failure mechanism.

The Test Set Up

Each clock had two feet and two push buttons on the opposite edge. (That was the manufacturer’s form of snooze button; by pressing anywhere on the top of the clock the buttons would depress and both allow you to “snooze” and the LED would start it’s light pattern if it was not in the full ON position.) Because of these natural isolators we chose to mount the clocks upside down for the test for better contact with the table.

This photo also shows a close up of the fixturing with the “response” accelerometer mounted just above the clock. The legs can also be seen here. The “reference” accelerometer is mounted just behind the test item. (The blue cable to it can be seen in the background.) Accelerometer cables were taped down during testing.
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Mounting Configurations for Each Test

<table>
<thead>
<tr>
<th>Test Sample Number</th>
<th>Axis</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>Mounted upside down</td>
</tr>
<tr>
<td>2</td>
<td>X, Y and Z combined</td>
<td>Mounted upside down</td>
</tr>
<tr>
<td>3</td>
<td>Z</td>
<td>Mounted upside down, Center of table</td>
</tr>
<tr>
<td>4</td>
<td>Z</td>
<td>Base of unit only, cover removed, right side up, Slightly to the side</td>
</tr>
<tr>
<td>5</td>
<td>X, Y and Z combined with rotation</td>
<td>Mounted upside down</td>
</tr>
<tr>
<td>6</td>
<td>X, Y and Z combined with rotation</td>
<td>Mounted right side up</td>
</tr>
<tr>
<td>7</td>
<td>X, Y and Z combined with rotation</td>
<td>Mounted upside down</td>
</tr>
<tr>
<td>8</td>
<td>X, Y and Z combined with rotation</td>
<td>Mounted upside down, Center of table</td>
</tr>
<tr>
<td>9</td>
<td>X, Y and Z combined with rotation</td>
<td>Mounted upside down, Slightly to the side</td>
</tr>
<tr>
<td>10</td>
<td>Y</td>
<td>Mounted upside down</td>
</tr>
<tr>
<td>11</td>
<td>Y</td>
<td>Base only, mounted right side up</td>
</tr>
<tr>
<td>C</td>
<td>Control</td>
<td>No test</td>
</tr>
</tbody>
</table>

Note: Items with the same color on the chart were tested together. Unit 5 was removed at 2.5 minutes and replaced because of LCD failure which was assumed to be close to an “out of box” failure; however, once the vibration was stopped the LCD started working again with no problems.
The Test Findings

Types of Failures

One of the unexpected findings was that there was more than one failure mode for the LEDs. Not only would they flicker, and for two of the items completely go out, but another mode was that the colors would stop cycling through all seven colors. Red was the first color of the cycle, and when wear started to occur there would be times when two or three colors would cycle and then default back to red, then red only. Once in a great while it might change to green (the second color in the cycle) but immediately go back to red.

An unexpected failure was that the plastic of the case around the LCD screen would start to powder. This did not happen in every single test, but in the tests where it did there was a different powder pattern for different axes. In many cases there was also powdering on the AAA batteries. See Figures 1 & 2.

Figure 1 - Powdering of plastic case
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Figure 2 - Powdering on Batteries

Another failure was in the LCD screen. There were times when half of it would go blank, or stripes of it would. In more than one case it went completely blank. With Unit 5 the screen went blank after just 2.5 minutes of vibration but once it was removed from the table the LCD worked fine and continued work afterward.

Test Schedule

The test schedule used was a modification of the ground vehicle vibration profile from MIL-STD-810G which was based on measured data. It was provided by Skip Connon of Aberdeen Proving Grounds, and our thanks go to him for his help. In his words, “the schedules were a higher frequency version of the Composite Wheeled Vehicle schedule from 810G to comply with the displacement limitations”. (See graph on next page.)

The only thing that was modified from this profile for the test was the displacement. The Tensor has low displacement. The acceleration factors were all met.
MIL-STD-810G Acceleration PSD
Composite Wheeled Vehicle
Low Displacement Spectrum
**Test Interruption**

There were times when the testing was paused either for facility adjustments or to get a closer look at the item(s) under test. The guidance from MIL-STD-810G on test interruptions was used and at no time was there an overtest situation.

**Rationale Behind Test Choices for Testing More Than One Item at a Time**

Originally the intent was to test one item at a time. However, since there were extra clocks and it was a once in a lifetime opportunity I wanted to make as much out of the tests as possible. We had removed one cover from a clock to see what the internal components were, and I realized that by testing a sub-assembly alongside a full assembly that it would be possible to see if any of the components failed more quickly. (This could be similar to a Qualification test vs. a Design Reliability test). We did, indeed, find that the specific failure we were looking for occurred more quickly at the sub-assembly level in the Z axis test – in roughly half the time - though not at all in the allotted time when we tested on the Y axis only.

In another case I made the decision to have one unit upside down and flush to the table while the other unit was right side up. We found a failure in the upside down unit but the right side up unit didn’t seem to show any effects from the testing at all. Because of the two buttons acting as vibration isolators, no sign of failure was ever found in the unit sitting right side up. This gives an important reminder about test orientation. Anything that is shipped, even if in a box marked “This Side Up”, has the possibility of ending up in a number of different configurations and one of those could be especially stressful.

In the X, Y, Z with rotation added test where I had two units in the exact same configuration but side by side, one was purposely set directly in the center of the table and one was slightly off to the side. I had been told by Team that I should see more energy in the unit off to the side, and indeed that showed flickering in the LED first. However, the full failure was instantaneous between the two units. That is a good lesson that knowing that something is weakening is still often not a valid indication of how much life is left in it.

One anomaly was found while testing unit #9. We needed to pause the test to make a facility adjustment, and the LED for #9 had stopped. During the short resting period it started working again and continued to work until the end of the test when it stopped working completely and did not recover. An important lesson to learn from this is that while something might test out perfectly during a bench test it does not mean that it will necessarily work well while in full operational mode and under environmental stress.

Every one of the clocks kept perfect time throughout the test. Each was started at its default setting, and when testing clocks in the past I’ve often found the internal timer would reset to the default of 12:00. That did not happen once during this test. (This is not a sign of any weakness of this test; only a side note on what could have been another failure mechanism.)
I needed to leave to catch my flight before the final test (Y axis) was completed. I took the control clock with me and one base (which still worked) to use as examples when I teach. The people at Team took the photo I’d asked for of the remaining ten units after test.

If you look closely you can see some of the powdering patterns on the cases (first and second units from the left on the top row and the first, second and third units from the left on the bottom row) Some of the LCDs are dimmer than others, and the unit on the bottom right is showing uneven fading. The time showing on the faces each started at the default.
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Plotting It Out

<table>
<thead>
<tr>
<th>Vibration Axis</th>
<th>Time to Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>X Y Z w/rot</td>
<td>36 minutes for upside down unit (as others were tested), did not fail right side up</td>
</tr>
<tr>
<td>X Y Z w/rot (center)</td>
<td>Center of table 15 minutes, slightly off to the side 11 minutes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Axis</th>
<th>Time to Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>40</td>
</tr>
<tr>
<td>Y</td>
<td>No flicker found at the end of 150 minutes</td>
</tr>
<tr>
<td>Z</td>
<td>81</td>
</tr>
<tr>
<td>X, Y and Z simultaneously</td>
<td>41</td>
</tr>
<tr>
<td>X, Y and Z with rotation</td>
<td>2.5</td>
</tr>
<tr>
<td>No flicker found at the end of 150 minutes</td>
<td></td>
</tr>
<tr>
<td>Complete failure of LED</td>
<td></td>
</tr>
<tr>
<td>No failure</td>
<td></td>
</tr>
</tbody>
</table>
Lessons Learned

1. The hypothesis behind the test was proven out: That using vibration to excite X, Y and Z axes at the same time will not easily correlate to any assumptions made trying to add single axis excitation numbers together.
2. Orientation can definitely make a difference.
3. Sub-assemblies will show weakness more quickly than full assemblies.
4. Different samples using the same test schedule (profile) may have very different times to failure (presumably because of shifts in production).
5. The failure being tested for may not be the first failure to occur.
6. It takes a team to do the best testing (more than one set of eyes on the test and each with their own area of expertise).
7. Testing done as an experiment gives latitude for changes in the initial test plan in order to find data that can be the most useful.
8. Some things (such as the beginning of lights flickering) can be seen more quickly through a camera lens than by the human eye.

Note of Appreciation

My sincere thanks go to the following organizations and people:

Team Corporation

Not only did they allow me to use their equipment but they showed me great warmth and kindness while I was at their facility. The entire group was enthusiastic, willing to help, and a pleasure to work with.

Skip Connon

Thanks to Skip we had a vibration schedule to work with that was based on measured data. He understood in advance that the test items were not defense hardware and were never meant to be used as such yet chose a profile for us to use that would be well known and respected. I truly appreciate all of the help he gave the team.

H&H Environmental Systems, Inc., especially Howard Cragg

H&H supported our every effort. They purchased the clocks and shipped them in, paid my travel expenses, and are allowing me to publicly present the results at various venues and to distribute this whitepaper at no charge. I appreciate Howard’s belief in me and his willingness to back my ideas.