Time-to-Failure Testing Using Single- and Multi-Axis Vibration

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A Tensor™ 18kN vibration system from Team Corporation was used to run time-to-failure tests on 10 digital alarm clocks. A malfunction onset in the light emitting diode (LED) display was used to indicate failure. Time-to-failure was compared for both single-axis and multi-axis vibration excitation.

The hypothesis for this test was that vibration excitation in the X, Y and Z axes simultaneously would cause a different failure rate (presumably shorter) than using excitation in any single axis. To make the results more traceable, only one failure mechanism was looked at – the reaction of the LED. That does not presume that an LED failure would be the only failure found. Other failures would be expected. However, if the test was stopped as soon as any failure (or weakness) was found, then all it would really show would be the likely first failure on each single axis. The idea was to track one particular failure mechanism. The experiment was designed by the author, representing H&H Environmental Systems, Inc., who oversaw all testing. Joel Hoksbergen did the majority of the fixturing work and operated the Tensor, while Chon Mech managed the vibration system controller.

Most labs that run vibration tests have only single-axis shakers. In some cases, they can be rotated so a Z-axis shaker can operate as an X- or Y-axis shaker. This often requires a different testing fixture. Combining shakers without a full understanding of their limitations can damage the shakers. On the Tensor, the same fixture can be used. Therefore, when doing a test on an item that needs to be excited 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.

Test Items

Twelve clocks were purchased from Amazon.com by H&H Environmental Systems and shipped in advance to Team (see Figure 1). 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, the clock 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 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 × 79 × 78 mm (3.1 × 3.1 × 3.0 inches).

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 a liquid crystal display (LCD) unless two units are compared. One unit was pulled apart so that the components could be identified and was later tested that way. It was decided to test a second unit that way also. Each test unit got a piece of masking tape with a hand-written number to differentiate them for analysis and reporting purposes. They were numbered 1 through 11 and C for the control unit.

Test Item Considerations

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:

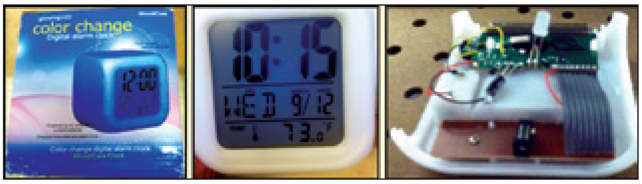

Figure 1. Details of the 12 digital clocks used as the devices under test.

- Easily available
- Non-proprietary
- Inexpensive
- A number of failure modes to look for:
  - Clock can be measured against other time keeping equipment to see if the timer malfunctions
  - LCD could blink, be partially visible, or go completely blank
  - LED could flicker, lock into one color, blink on only once in a while, or completely stop
  - There could be structural damage such as cracks, flaking, wires loosening, etc.
- 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.

Vibration Exciter

A Team Tensor 18kN system was used for these tests. The Tensor is a fully contained multi-axis vibration test system capable of precise control of all six degrees of freedom. The system can reproduce real-world vibration environments by simultaneously exciting all three linear translations as well as all three rotations. The goal is replication of real-world vibration environments in all six DOFs.

The Tensor has 12 single-axis, electro-dynamic (ED) shakers; four in each of the X, Y and Z axes. For X and Y, the shakers are paired directly opposite each other. The shaker is capable of vibration in the following axes:

- X – longitudinal
- Y – transverse
- Z – vertical
- Roll – rotation about X controlled by Z
- Pitch – rotation about Y controlled by Z
- Yaw – rotation about Z controlled by X and Y

Controlling to a single axis on this unit is considered to be six DOFs, because the other axes are being controlled to a very small level. (The shakers in the other axes minimize cross-axis motion.)

Vibration Fixture

Fixturing was kept lightweight and simple. A piece of UHMW (ultrahigh-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. Figure 2 shows how the fixture was modified to hold both a full assembly (clock) and a sub-assembly (base unit) at the same time for comparative testing.

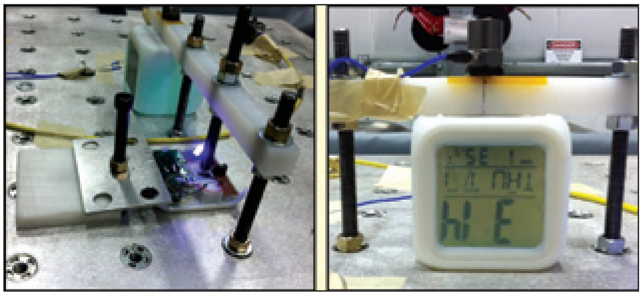

Figure 2. Details of DUT fixturing.

Figure 3. typical controller display.

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 testing. While it was firmly in place, no wear was seen on the base after testing, which proves that it was not torqued 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

Four Meggitt-Wilcoxon Research Model 993A tri-axial accelerometers were used for **Control**, one near each corner of the table. A PCB single-axis accelerometer was mounted in the Z axis on the fixture directly above the test item, and a second accelerometer was mounted on the table nearby. We named the sensors "response" and "reference." Response was only to get a general idea of what the test item was seeing, and reference was to get a measurement of the table right next to the item.

Data Acquisition and Control

The system was controlled by a Data Physics SignalStar Matrix system. Data acquisition and control was provided by an Abacus system, and 26 channels were used – 12 inputs for the tri-axial accelerometers; 12 outputs which were connected from the **Drives** to both the amplifiers and the Abacus units; one input channel for the response accelerometer and one input channel for the reference accelerometer. The operating system was Windows Vista. All six axes and rotations were controlled even if only one axis was excited. Figure 3 shows 15 graphs that display data simultaneously, 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 the accelerometers.

The table was leveled Before each test was started. A pretest 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.

The main limitation was time. We had two and a half days to complete as many tests as possible, so we needed to put a 2.5-hour

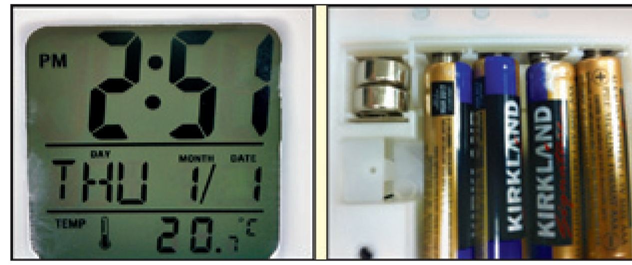

Figure 4. Powdering of plastic case and on batteries.

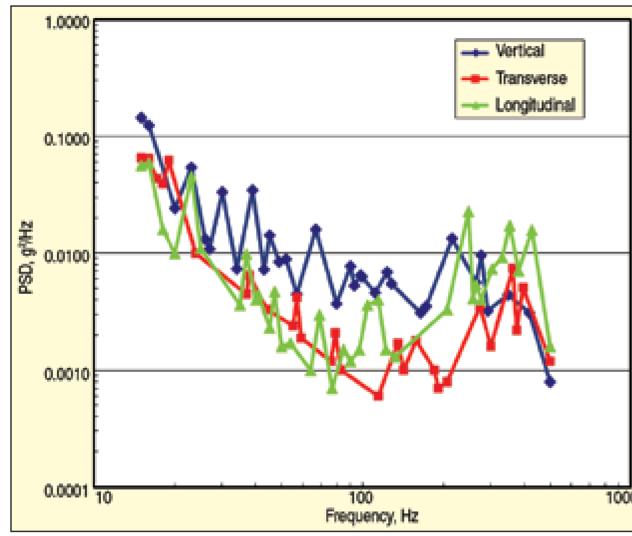

Figure 5. MIL-STD-810G acceleration PSD composite wheeled vehicle low-displacement spectrum used for the tests.

cap on each test. We would have preferred to have had the time to test to complete failure. Therefore, the first item to show signs of wear determined the main failure mechanism.

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.

Test Results

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 (two of the items went completely 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 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 Figure 4).

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 to work afterward.

Test Schedule. The test schedule shown in Figure 5 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." The only thing that was modified from this profile for the test was displacement. The Tensor has limited displacement. The acceleration factors were all met.

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.

Test Rationale. Mounting configurations for each test are shown in Table 1. Originally the intent was to test one item at a time. However, since there were extra clocks, we wanted to make as much out of the tests as possible. We had removed one cover from a clock to look at the internal components. We realized that by testing a subassembly alongside a full assembly, 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 subassembly 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, we 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 ill effects from the testing. 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 test of X, Y and Z with rotation added and with 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. Team said that we 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. Knowing that something is weakening is still often not a valid indication of how much life is left.

One anomaly was found while testing unit nine. We needed to pause the test to make a facility adjustment, and the LED for this

Table 1. Mounting configurations for each test.

Sample No.	Axis	Notes
1	X	Mounted upside down
2	X, Y and Z combined	Mounted upside down
3	Z	Mounted upside down, center of table
4	Z	Base of unit only, cover removed, right-side up, slightly to side
5	X, Y and Z combined with rotation	Mounted upside down
6	X, Y and Z combined with rotation	Mounted right-side up
7	X, Y and Z combined with rotation	Mounted upside down
8	X, Y and Z combined with rotation	Mounted upside down, center of table
9	X, Y and Z combined with rotation	Mounted upside down, slightly to side
10	Y	Mounted upside down
11	Y	Base only, mounted right-side up
C	Control	No test

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

Figure 6. Ten of the clocks after testing; one completely failed LCD.

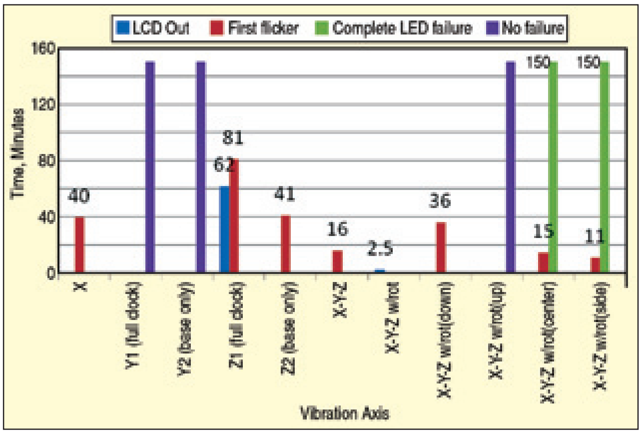

Figure 7. Time-to-failure bar graph of the tests.

unit had stopped. During the short rest 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 here is that while something might test 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.)

If you look closely at Figure 6 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. The time-to-failure results are shown in Table 2 and Figure 7.

Conclusions

- The hypothesis behind the test was proven: 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.
- Orientation can definitely make a difference.
- Subassemblies will show weakness more quickly than full assemblies.

Table 2. Time to failure per axis; full clock assemblies.

X	40
Y	No flicker found at the end of 150 minutes
Z	81
X, Y and Z simultaneously	41
X, Y and Z with rotation	36 minutes for upside-down unit (as others were tested), did not fail right-side up
X, Y and Z with rotation	Center of table 15 minutes;,slightly off to the side 11 minutes

- Different samples using the same test schedule may have very different times to failure.
- The failure being tested may not be the first failure to occur.
- Some things (such as the beginning of lights flickering) can be seen more quickly through a camera lens than by the human eye.

Acknowledgments

My sincere thanks go to the following organizations and people for their part in this experiment.

Team Corporation of Burlington, WA, was kind enough to allow me to come in and do the experiment. They build a variety of shakers, with the Tensor being their newest model. While they have people on staff who test the shakers to make sure that they are running correctly, they don't have a person who runs actual vibration tests. They supported the experiment, as well as assigning me two assistants, with the agreement that all data would be freely shared between us and with the request that I present my findings at SAVE (Shock & Vibration Exchange), regardless of the test results. They treated me with warmth, respect, and were a true joy to work with.

Skip Connon of *Aberdeen Proving Ground*, MD, an Army testing facility, provided the vibration schedule. APG does a great deal of ground vehicle vibration testing, and Connon is a member of the MIL-STD-810 Committee and helps to update each change notice and revision as well as other specification work. The seeds of the idea for this experiment came after hearing a report of another vibration experiment that Skip was involved in, and he was the first to hear the idea and give his input. I truly appreciate his guidance.

H&H Environmental Systems, Inc., especially *Howard Cragg.* I do consulting work for H&H and they backed my efforts on this experiment. They supplied the test items, paid my travel, and allowed me to do both the experiment and the follow-up reports on my consulting time. Among other things, H&H has a test lab and a training/mentoring program to help people get the best out of their testing. and they wanted to be at the forefront in investigating better ways of doing vibration testing.

I'd like to give a special thanks to *Norm Green,* my strongest backer, who believes in me and thinks of me as his shining star. His faith in me spurs me on to never be afraid to try new things but to be everything I can be.

This truly was a group effort and I am very grateful to all involved. S/V

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