Role of Accelerated Testing in Attaining High Reliability in Small Production Quantity Product

Douglas H. Loescher

Sandia National Laboratories

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Outline

- Operational definition of reliability
- Observations about small builds
- High reliability means delivered product does not fail
- Failure mechanisms, modes, and pathways
- Roles for accelerated stress tests
- Examples
- Summary

Reliable

- Product is reliable if it does not fail to do whatever it is supposed to do when it is supposed to do so
  - *Product* includes:
    - Hardware,
    - Processes,
    - Tests
    - Events
- Accelerated stress testing is an important tool for identification and possible quantification of failure mechanisms.

Supposed To Do

- It is the author's experience that *supposed to do* is often not clearly understood by the customer or the supplier
  - Examples:
    - Does a rise time requirement apply to all voltages from a multiple tap battery or only to some?
      - A typical requirement has been to have all voltages at some percentage of nominal in some number of milliseconds
        - Often, only a subset need meet the requirement
    - Does stoppage of count down and re-schedule of a field test, without damage to expensive and scarce assets, constitute failure of the test?

Small Quantity

- Much of the author's experience has been with total build quantities of between one and ten.
  - One item for a space platform,
  - Six batteries for weapon tests,
  - Five or fewer special electronic assemblies
  - One field test
- However, *small* applied to a build of 1000 one-shot electro-explosive devices for which the reliability requirement was 0.9999 (four nines).

Observations About Small Builds

- Limited budget
- Often severe limitations on hardware for test
- Evolution from development project to small build
  - Project starts out as demonstration of a concept
    - No reliability requirements
  - Successes snowball into more funding and more capability.
  - A customer with urgent needs and funding is found
    - Along with needs and funding come reliability requirements
    - People who did early builds no longer on project

Focus on Preventing Failure

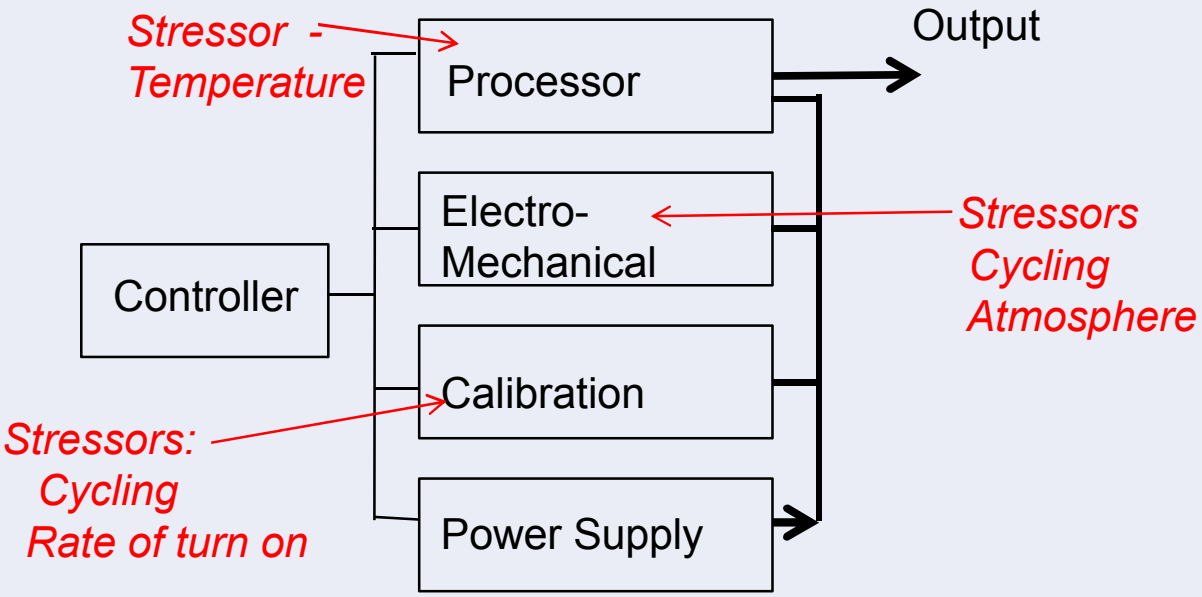
- Preventing failure in fielded product includes:
  - Identifying possible causes of failure
    - At design stage
    - During processing
    - During acceptance
  - Understanding causes of failure
    - Need to be as specific as possible
  - Eliminating causes of failure
    - Through redesign, changes in processing, changes in acceptance
- Goal –Delivered product does not fail

Roles of Accelerated Stress Testing

- Explore failure space with limited hardware and in limited amount of time
- Clarify association between stresses and failure
  - What stresses at what levels cause what failures
  - Identify synergisms between stresses
- Quantify relation between stress and probability of failure
  - Provide evidence that probability of failure due to particular stress is acceptably low

Example 1 - Terrestrial System

- Remote location terrestrial system



Calibration Module

- Incandescent bulbs used to calibrate sensors
  - Calibration about every two hours (120 minutes)
- Failure mechanism is very rapid heating of filament that occurs when current is applied from source with low internal impedance
  - Failure at turn on much more likely than failure while on
- Design incorporates controlled current ramp
- Accelerated stress
  - Cycled every three minutes, factor of 40 acceleration

Electro-mechanical Module

- Garage door like mechanism in corrosive atmosphere
- Accelerated corrosion and wear
  - Subject matter expert designed atmosphere in which corrosion would be accelerated.
- Modified cycle to reduce low-wear stationary time
  - Retained high wear part of up-down cycle
- Estimate obtained 30 % of corrosion and wear in 10 days.

Processor Module

- Signal processor electronics would operate continuously
  - No possibility of accelerating aging through reduction of duration of low stress periods
- Seven circuit cards were available for test
  - Tested at 65 C for 219 hours, extended to 1184 hours
    - Determined from Arrhenius relation to be equivalent to one year at 20 C (activation energy of 0.7 eV)
  - No failures were observed
    - Estimated reliability of 0.94 for one year at 90 % confidence
      - Reliability of 0.9 at 50 % confidence from 219 hour results

Example 1- Conclusions

- Life of calibration lamps would exceed required life
- Life of garage door mechanism would exceed required life
- Processor electronics would require periodic replacement
  - Replacement period consistent with logistics plan

Example 2 – Space system

- Two issues
  - Cleaning and bagging
  - Infra-red sensor degradation

Cleaning and Bagging

- Various mechanical parts and assemblies were cleaned in a Class 100 clean room and vacuum bagged for shipment to next assembly contractor.
  - Next assembly site on east coast and controlled by another contractor
- Contractor claimed sub 10 micron particulate contamination on shipped parts exceeded specification
- Multi-month cycle time for cleaning, bagging, and packing at Sandia; shipping; then receipt, incoming inspection, preparation and transmittal of report by contractor.

Cleaning and Bagging

continued-ii

- Possible sources of contamination
  - Processing at Sandia
  - Incoming inspection at contractor
- Social issue
  - Most comfortable to blame the other guy
  - Easiest to identify and fix locally
- Accelerate cycle
  - Clean, bag, walk around with bag in lab coat pocket, open bag and inspect for particles
  - Test on coupons rather than on hardware for delivery

Cleaning and Bagging
continued-iii

- Acceleration factor of about 360
  - Normal clean-bag-ship-inspect cycle took at least a couple of months
  - Accelerated cycle took about 4 hours.
- Quickly found that parts were contaminated as soon as they were put into a bag
- Confirmation of failure mode
  - No contamination observed on parts that were put into covered Petri dish before bagging.
  - Apparently small particles flake off of inside of bag

Infra-red Sensor

- High pixel count infra-red sensor array
  - Design includes barrier to separate gold and indium
- When in space, array will be cooled to 105 K
  - Room temperature storage between delivery to Sandia in 2009 and eventual use in space
  - Concern about diffusion and gold-indium intermetalic formation prior to launch

- Investigation of intermetalic formation
  - Located process evaluation coupons (PEC's)
  - Compared post storage electrical measurements with post fabrication measurements
    - Observed increased leakage current
  - Electron microscopy showed inadequate barrier coverage
- Accelerated stress testing on PEC's
  - Estimated that 100 hours at 50 C would be equivalent to 25 days at room temperature
  - Samples aged at 50 C showed expected degradation

Satellite Application-Conclusions

- Bagging source of very small particles
- Two solutions
  - Re-clean after bagging
  - Isolate part from bag
    - Petri dish
    - Complex, expensive metal “casket”
- Inter-metallic formation
  - Availability of PEC’s was critical to investigation
  - Ongoing studies to determine impact on required performance

A Field Test as a Small Build

- More common to think about reliability of what is being tested than about reliability of the test event
- Value in thinking of test event as production of a single item
  - What are reliability concerns?
  - What are failure modes?
    - Prepare fault trees for identified high level test failure events
      - A high level failure could be: All control room indications as expected but rocket engine fails to ignite
  - Apply accelerated stress testing to expose and provide information about failure modes

Two Illustrations From Field Test

- Concern about integrity of RS485 communication due to cable length
- Concern about over heating of fire signal module due to high ambient temperature and sun light.

Signal Degradation

- Concern that signal cable length was near or slightly in excess of recommended maximum of 1200 meters (4000 feet) for reliable use of RS485 protocol
  - Actual length was slightly over 4000 feet
- Reliability concern but no clear statement of what reliability was required
  - Remember earlier *Supposed to do* slide

Signal Degradation

continued-ii

- Accelerate stress
  - Identify stress- length of cable
  - Investigate relation between stressor and failure
    - Could test at various lengths and develop relation between length and reliability of communication
- Reliability perspective
  - Eliminate failure mode if possible
  - The customer chose to add a repeater to the signal path

Over Heating of Electronics

- Concern that electronics that produced electrical pulse to fire squib could over heat if test were delayed
  - Could be intense solar heating in afternoon in New Mexico
- Accelerated test
  - Measure temperatures that occur
  - Test modules in oven

Field Test-Conclusions

- Field test group decided to add RS485 repeater at intermediate point in cable path
  - Cheaper and more certain solution than accelerated test to determine effect of cable length
- Module over heating
  - Expect measurement of temperatures
  - Expect accelerated test

Caveats and Pitfalls

- Tests on isolated parts of product may miss interaction and interconnect failures
- Misleading results if misidentify the failure mode or the stressor
  - Accelerated cycling of *garage door like assembly* could have been misleading if principle failure mode was door getting stuck in place due to corrosion
- It may be more expensive to evaluate a failure mode than to eliminate it
  - Cheaper and more certain to add repeater than to explore effect of cable length on communication reliability

Summary

- High reliability will be attained if product does not fail
- Accelerated stress testing is an efficient and cost effective tool for achievement of high reliability in small build product
- Use accelerated stress test for all of the following was shown:
  - Identify failure modes
    - With as much clarity and specificity as possible
    - Example –failure of calibration lamps

Summary continued - ii

- Determine associations between failure modes and stressors
  - Example – Bagging study
- Determine bounds on probabilities of failure
  - Example - Circuit card tests at elevated temperature
- Show that probability of failure is low enough
  - Example - Cycling of incandescent bulbs
- Explore relationship between probability of failure and stressor levels
  - Example – Proposed study of relationship between cable length and communication channel reliability

Summary-iii

- All together on one slide
  - Product is reliable if it does not fail
  - To achieve reliability, eliminate failure
  - Accelerated stress testing is a power full, cost effective tool with which to identify and gain knowledge about failure
  - Treasure testable items, for example process evaluation coupons
  - Be imaginative
    - Think of a field test as delivery of one very reliable unit