Cincinnati Sub-Zero

Environmental Stress Screeing

Reduced Cost – Increased Profitability – Satisfied Customers

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Introduction

- The objective of Environmental Stress Screening is to tailor a screen which will precipitate and detect latent defects as early as possible in the manufacturing cycle, where it is the most cost effective to correct.
- ESS is a process, and it must be controlled. Without control, repeatability, and reliability, the screen would be questionable. The dynamic and thermal profiles for establishing an ESS process are not rigid rules. They are only guidelines.

ESS traditionally increases product reliability four times that of unscreened electronics.

What is ESS?

Environmental Stress Screening (ESS) is a means of screening electronic assemblies at the most cost-effective point of manufacture to expose defects that can't be detected by visual inspection or electrical testing. These defects are typically related to defective parts or workmanship and are normally found as early field failures.

ESS works by subjecting 100% of a group of products to an environmental stimulus or a set of stimuli for a predetermined time for the purpose of forcing failures to occur before shipment, in fact, at the board level.

Failures are normal and expected when ESS is applied. This makes ESS radically different than more conventional certification testing which requires failure free operation as proof of reliability.

ESS is not a test, it is a process.

Key factors for proper ESS implementation are:

1. The stress environment must not exceed the electrical or mechanical limits of the product.
2. An optimum level of stress must be applied to the product.

Expected benefits of a properly applied ESS program are:

1. Reduced field repair expense
2. Fewer defects and waste
3. Elimination of less effective screeningprocedures
4. Lower unit cost
5. Increased product value
6. Improved customer satisfaction
7. Better return on investment (ROI)

Advantages of Temperature Cycling

Many independent studies have been conducted analyzing the effectiveness of various types of ESS processes.Conclusive data has been compiled by many manufacturers of electronic assemblies supporting today's thinking that temperature cycling is the most effective type of screening process.

While it has been demonstrated that both temperature cycling and random vibration together is the most effective screen in terms of identifying latent defects, if a single screen is to be used, temperature cycling is considered to be the single most effective screen in identifying latent defects. According to the ESSEH guidelines, temperature cycling regularly detected an average of two-thirds more latent product defects than with random vibration alone, which is ranked second most effective in identifying defects.

Stress uniformity is without question the most important aspect of the screening process. Temperature cycling provides the additional advantage of a uniform stress environment when air flow across the product is tightly controlled. All areas of the product must be subjected to an equal amount of stress throughout the screen profile. Some other methods of screening do not offer this uniformity across the product.

When temperature cycling is put in place as a manufacturing process, it takes less time to perform than most other types of stress because of its ability to quickly force a greater number of defects into failure. Though vibration has a shorter cycle time, it doesn't reveal as many defects. Therefore, the overall efficiency of temperature cycling is higher.

Basic parameters of temperature cycling are: temperature extremes, rate of temperature change, temperature uniformity across the product, and number of cycles.

Design for the environment

The environment to which a product is subjected must be considered early in the design stage - not as an after-thought when you know you have a problem. The following points should be clearly defined early in the design stage: Safety, Operating Environment, Mode of Transport (land, sea, and air), and geographic considerations.

For an effective screen, you should set temperature extremes as far apart as possible. Keep in mind the temperature limitations of the components on the board. The minimum range between hot and cold should be 100°C.

The rate of change of air temperature impinging on the part is 5°C to 20°C/minute, with the emphasis again on uniformity across all products in the chamber.

Uniformity will be controlled by air velocity across the product, with a recommended minimum of 750 FPM.

Careful monitoring of the ESS process will help determine the number of cycles needed for the chosen rate of temperature stress. Start with 30 cycles and monitor failures. Number of cycles can be reduced until percentage of failures begins to fall off. This will be the most efficient screen.

Failure Analysis

The long term success of an ESS program depends on how well the results are monitored. After a proper implementation, monitoring is the only measuring stick for ROI (Return on Investment).

Sometimes it is necessary to review a screening program. For example, new suppliers, new assembly methods, sudden drop in in-house failures, or increase in field failures.

Determining the root cause of a failure is essential in a closed loop screening program. If the cause can be tracked then it can be corrected. Remember, a very high percentage of failures can be traced to manufacturing problems. Follow-up in ESS is essential because the program is based on field failure analysis. It is only logical that the analysis would continue throughout the process.

ESS is a tool to reduce field failures, not an end to itself. Therefore, monitoring also provides a basis for assessing change in part selection, manufacturing processes, screen effectiveness, and responding with appropriate action.

Implementation

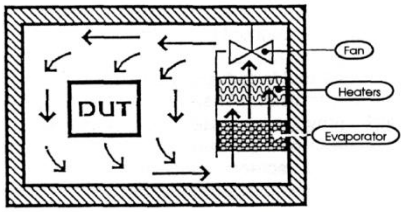
In order to guarantee success, ESS must involve careful research, a well defined set of objectives, and a monitoring system for the closed loop process.

Equipment

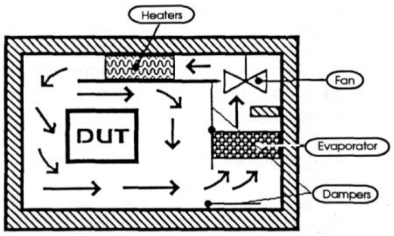
It has been established that temperature cycling is an effective tool for improvement of the quality of manufactured products and associated reductions in field failures and their related cost to the manufacturer in both dollars and customer satisfaction.

There are three types of chamber design currently being used for ESS. Design selection is dictated by the temperature transition rate required.

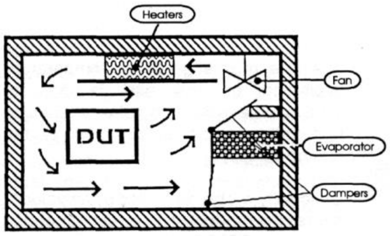
a) Less than 10°C/min - Traditional Design
b) 10°C/minute to less than 20°C/minute - "Isolated Evaporator"
c) 20°C/minute and up- Air-to-Air Thermal Shock



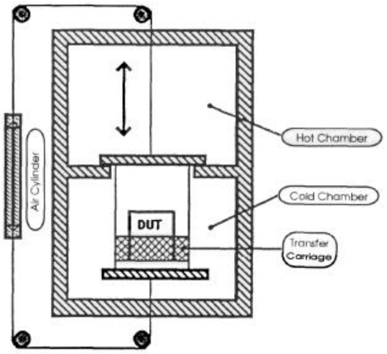
Traditional Chamber Design
Evaporator coil is thermal cycled and is thermal load on cooling system



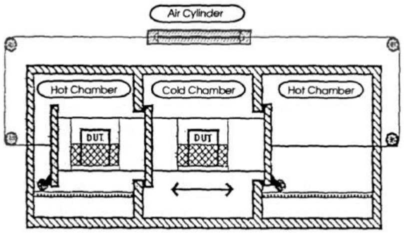
Isolated Evaporator Design
Dampers direct chamber air through evaporator (cooling mode)



Isolated Evaporator Design
Dampers isolate evaporator which is kept cold by refrigeration system



Air-to-Air Thermal Shock Chamber
DUT is moved between pre-conditioned hot and cold chamber



Double Duty Air-to-Air Thermal Shock Chamber
Cold chamber is utilized 100% of the time

Traditional Design

The traditional chamber design places the cooling coil in the chamber proper, behind baffling and then uses a fan or blower to circulate the air through the chamber and the coil to provide cooling. During thermal cycling, the evaporator is thermal cycled along with the rest of the chamber, which places a load on the refrigeration system. Because the size and weight of the evaporator are proportional to the horsepower of the refrigeration compressors, there is a practical limit to how fast a chamber of this design can thermal cycle. As more refrigeration horsepower is added, the larger and heavier the evaporator becomes. A point of diminishing returns is soon reached.

Isolated Evaporator

The isolated evaporator chamber design effectively removes the evaporator as a cooling load in the chamber. The evaporator is isolated from the chamber in its own insulated compartment and is kept cold during the entire thermal cycle. A series of dampers operated by the temperature controller open during the cold cycle and meter in the appropriate amount of cold air to meet the chamber cooling requirements. Since the evaporator always stays cold, it is not thermal cycled along with the rest of the chamber and does not present a cooling load on the refrigeration system. In theory, unlimited refrigeration horsepower could be applied to this design along with appropriately sized evaporators without increasing the thermal load of the chamber and its contents.

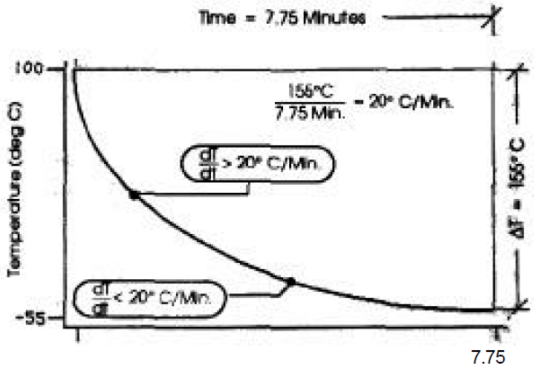
Air-to-Air Thermal Shock Chamber Design

The air-to-air thermal shock chamber design provides the advantages of an isolated evaporator while overcoming the effect of refrigeration system response time delay during rapid thermal cycling and at the same time reducing the "thermal overhead" that must be cooled and heated in addition to the DUT.

The air-to-air design utilizes preconditioned hot and cold chambers and then transfers the DUTs rapidly between them to accomplish thermal cycling. This design also permits overconditioning (spiking) of the chambers slightly beyond the required temperature extremes to hasten the speed at which the DUT achieves its target temperature. Because current ESS guidelines are recommending temperature transition rates of 20°C per minute, the air-to-air shock chamber is the preferred design.

Average vs. Linear Temperature Transitions

In the earlier days of ESS, environmental chambers offered air temperature cycling transition rates on the order of 5°C per minute. This transition rate was often referred to as "average" by most chamber manufacturers. In reality, during an average rate temperature transition, the air temperature rate of change may vary greatly from the average rate. For temperature pulldowns with mechanical cooling, dT/dt will be much greater than the average in the early stages of the pulldown and much below the average as the low temperature extreme is approached. When plotted out, the time/temperature relationship is a curve with a steeper slope at the beginning of the pulldown and a flatter slope at the end, but nevertheless resulting in some average transition rate for the complete pulldown.

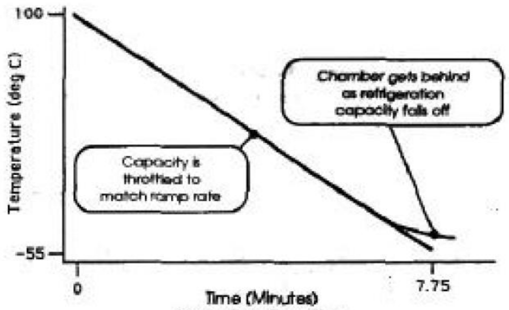


Time (Mintues)

AVERAGE RATE OF TRANSITION

Chamber runs of full capacity producing average pulldown transition rate

If a temperature programmer is used, the temperature setpoint can be sloped at the exact rate desired, generating a linear ramp between the temperature extremes. The chamber will respond by tracking the setpoint as closely as possible within its performance capabilities. Although the chamber is capable of cooling much faster than the ramp early in the pulldown, the programmer throttles back thechamber's cooling capacity to match the linear ramp. On the surface, this may appear to present no problem, however, as the pulldown progresses, the chamber will reach a point at which the chamber does not have sufficient pull-down rates to follow the ramp even at full capacity. At this point dT/dt will begin to drop below the linear ramp rate and the temperature will begin to "fall behind" the ramp, ultimately taking longer to reach the low extreme than the same chamber running an average rate pulldown.



Time (Minutes)
Linear Rate Transition
Capacity is throttled to match ramp rate

In general, an average rate pulldown will require less cooling capacity than a linear rate pulldown, all other things being equal. Depending on the actual transition rates required, this capacity difference can be as much as a factor of two.

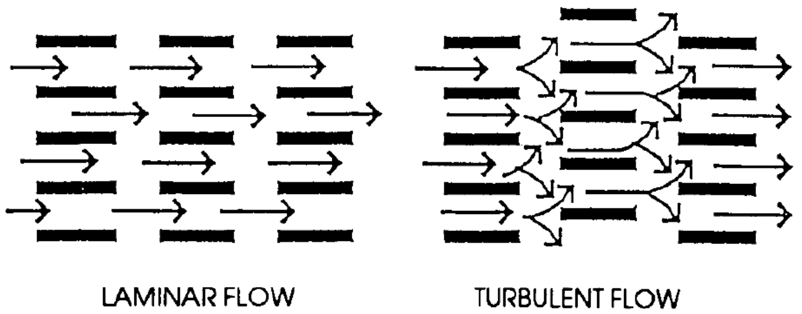
Air Flow

An aspect of thermal cycling chamber design often overlooked is the matter of recirculated air volume and velocity over the DUT. This relationship can be qualitatively illustrated by considering the phenomenon of "wind chill". Most winter time weather reports will include, in addition to air temperature data, an equivalent wind chill value. For example, a 20°F temperature combined with a 20 mph wind yields a wind chill of -10°F. This does not mean that this combination of temperature and wind velocity can cool objects to -10°F. It means that under these conditions the wind can remove heat from an object at the same rate as still air at -10°F.

In convective heat transfer from a solid object to a fluid such as air, the object first heats up the air immediately next to itself. This effectively reduces the temperature difference between the object and the air. As this temperature difference decreases, the impetus for transfer of more heat is reduced and the rate of transfer of heat from the object decreases. If this "boundary layer" of air immediately next to the object is constantly moved away and replaced by forced air convection, a larger temperature difference between the object and the air can be maintained and the rate of heat transfer is increased.

In order to maximize the heat transfer from the DUTs in an ESS chamber, high velocity recirculating air flow should be provided within the chamber. A practical limit beyond which further velocity increases produce little added benefit is approximately 750 feet/minute. Thermal studies show that under these conditions, the DUT temperature will trail the chamber temperature by only a few degrees, so the DUT surface dT/dt nearly matches the chamber air dT/dt, and the soak time at the extremes can be shortened or eliminated altogether reducing overall test time.

This relationship is further illustrated if one examines the design of many conventional environmental test chambers on the market today. Even in A.G.R.E.E. chambers designed for "rapid" thermal cycling with large mass loads, air flow is often marginal. This is why soak periods of several hours or more are required to insure that the DUT has stabilized at the temperature extremes. Because most thermal cycling specifications only address air temperature transition rate, it is not unusual for a chamber builder to actually reduce the pitch of the chamber fan blades to reduce air flow, to reduce the heat pick-up from the DUT, and enable the chamber to just "squeak in" under the specifications. Low air velocity may have its place in "design qualification" testing where test realism is important, but to ESS applications, the more air flow, the better. DUT orientation can also work together with chamber air flow to further enhance heat transfer. Because turbulent air flow transfers heat more efficiently than laminar flow, the arrangement of multiple DUTs in the chamber should encourage turbulent air flow.



DUT orientation effects air flow. Turbulent air flow enhances heat transfer from DUTs

Moisture Management

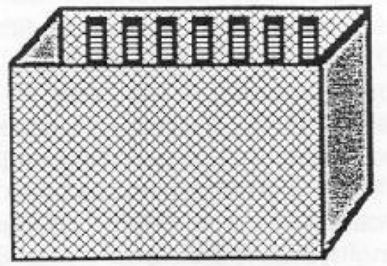
Thermal cycling at rapid rates has the potential of causing moisture or frost to form on the DUTs. This generally happens on the upward temperature ramp, and is most severe in the traditional chamber design. As the chamber air is cooled during the pulldown, it contracts drawing ambient make-up air in through the chamber's port plugs, past the fan shaft seal, the door gaskets, and other penetrations in the chamber. The moisture in this air condenses and produces frost on the evaporator. The evaporator holds the frost until the heating cycle starts. Then, as the temperature rises, the moisture leaves the evaporator and migrates to the coldest surface in the chamber which is generally the DUT, producing frost or condensation there.

There are three ways to prevent this condensation frost on the DUT:

1. By purging the chamber with dry (-100°F dewpoint) nitrogen or air, creating a slight positive pressure within the chamber, the migration of moist ambient air into the chamber during the pulldown is prevented.
2. A small dewpoint coil operated at the low temperature extreme and located out of the main chamber air stream will have little effect on the chamber but will attract any moisture to itself, keeping it off the DUT.
3. High velocity air flow over the DUT will cause its temperature to closely track the chamber air temperature keeping the DUT's temperature above the dewpoint and preventing condensation.

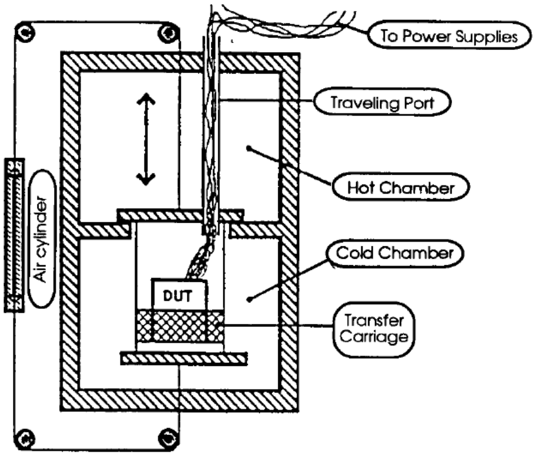
This keeps frost off the DUT. However, we must then manage the elimination of the frost from the chamber. Therefore, the chamber should be equipped with a defrost system. The hot gas approach works well for isolated evaporator design and is best manually initiated by the operator at a convenient time. Electric heaters for defrost in the traditional and the air-to-air shock design offer the additional advantage of permitting the cold chamber to operate as a full range chamber for other occasional testing purposes.

Electrical Interconnection



Simple Basket With Inerconnection for DUT's on backplane of Basket

While a good number of environmental stress screens may be designed with the DUT passive, i.e. unpowered, there are certain to be a significant number of screens that can benefit from some DUT power-up or power cycling. In these cases, certainly the most bothersome problem to be addressed is the matter of maintaining reliable electrical connections to the DUT. While the DUTs themselves are subjected to the screening process only once, the power cabling and connectors are subjected to the screening environments repeatedly.



Air to Air Thermal Shock Chamber
DUT is moved between preconditioned hot and cold chamber

The conventional method of providing power to a number of DUTs in an air-to-air shock chamber in which the DUTs are moving between the hot and cold zones is via a "traveling" port that extends from the transfer carriage out through the hot zone to the outside world. Because the port tube is rigid, any flexing and bending of the cable bundle takes place at ambient conditions outside the chamber's hot or cold environment. However, over a period of time, this repeated flexing takes its toll, so the cabling will require periodic maintenance or replacement.

Once power is made available at the transfer carriage, it must be distributed to the individual DUTs. Again, this can be a very troublesome area. Although only minimal flexing of wiring takes place here, the screening environments can eventually fatigue and weaken solder joints causing intermittent power loss. DUT mating connectors also are subject to wear and breakage caused by repeated usage. The primary design consideration is ease of connector replacement. In designing this fixturing, it is best to assume that connectors that mate with the DUTs are expendable items, and make them easy to replace.

Instrumentation

Each of the three chamber designs require different control systems for controlling chamber temperatures. Traditional chambers require more traditional type controllers, microprocessor based programmable, with digital display and high/low alarm. Isolated evaporator requires a more sophisticated control system, because temperature control is achieved by opening and closing dampers using linear actuators. For more precise control, thermal shock requires not only temperature control, but also a cycle timing and counting system to sequence the movement of the transfer carriage.

Because the motion of the transfer carriage can create potential pinch points, the transfer mechanism must be interlocked for operator safety. Limit switches on the chamber doors should be provided to prevent motion of the transfer carriage when any of the doors are open.

Additional temperature measurement and/ or recording devices may be included to monitor or document the screen.

References

Institute of Environmental Sciences, Journals and Publications
940 East Northwest Highway
Mount Prospect, Illinois

Methodologies and Techniques of ESS
Schlagheck J.G.
6839 Ashland Drive
Cincinnati, Ohio

A Systematic Approach to ESS
Eddy Weir

Chamber Design for ESS
Various CSZ Publications

Cost Justification

Generally Accepted Repair Cost

Board Level	$10.00
System Level	$100.00
Field Level	$1,000.00

History of Failures as a Percent of Production

Board Level ___________ %

System Level ___________ %

Field Level ___________ %

Cost of Repair before ESS

___________ boards/day x ___________% of failures x $10.00 x 270 days/year = ___________

___________ assemblies/day x ___________% of failures x $100.00 x 270 days/year = ___________

___________ fields/day x ___________% of failures x $1,000.00 x 270 days/year = ___________

Total Annual Cost = ___________

Cost of Repair after ESS

___________ boards/day x ___________% of failures x $10.00 x 270 days/year = ___________

___________ assemblies/day x ___________% of failures x $100.00 x 270 days/year = ___________

___________ fields/day x ___________% of failures x $1,000.00 x 270 days/year = ___________

Total Annual Cost = ___________

Annual Savings with ESS = ___________

Typical Applications

Traditional Chamber Design

Board/Computer Manufacturer

- Roll-In Fixture Supplied by CSZ
- Air Flow Vertical 1000 ft/min
- Capacity 60 Boards
- Operational Powering of Product throughout the temperature Cycle
- Rate of Change: 10°C/Minute Average
- Number of Cycles: 15

Design Modifications:

- Cart included plexiglass side panels (not shown) which forced all of the air up and through the product.
- Fixture wiring is isolated out of the air stream to reduce effects of the screen on the wiring.

Isolated Coil Design

Computer & Chip Manufacturer

- Board Level Screening
- Fixturing by Customer
- Air Flow Min.: 1000 feet/minute
- Non-Powered
- Capacity: Four fixtures with up to 72 boards
- Rate of Change: 1 to 20°C/Minute Average
- Programmable Control: ±3°C Anywhere in the Ramp

Air-to-Air Thermal Shock

Chip Manufacturer

- Component Level Screen
- Fixturing Provided by Customer
- Horizontal Air Flow: 500 feet/minute
- Powered During Heat Cycle Only
- Capacity Variable with Product
- Rate of Change : 20°C/Minute Average
- Number of Cycles: Unknown

Air-to-Air Thermal Shock

Government Facility

- Board Level Screening
- CSZ Fixture
- Vertical Air Flow
- Non-Powered
- Capacity Variable
- Rate of Change : 20°C/Minute Average
- Number of Cycles: 6
-

Cincinnati Sub-Zero