Stress Screening Chamber Selection and Implementation

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1.0 Introduction

The purpose of this paper is to serve as a tutorial for an engineer implementing a new production stress screening program. This paper will provide guidelines for:

a. equipment selection based on a given set of stress screen performance requirements
b. information to properly implement the stress screening system
c. methods to calculate best case chamber performance.

2.0 References

1.1 *'Environmental Stress Screening Guidelines for Assemblies'*, Institute of Environmental Sciences, 1990

1.2 Hobbs, G.K., HALT, HASS, *Precipitation and Detection Screens*.

1.3 Kececioglu, D., Sun, F.,*'Environmental Stress Screening'*, Prentice Hall, 1995

1.4 Kececioglu, D., Sun, F., *'Environmental Stress Screening : Its Quantification, Optimization and Management'*, Prentice Hall, 1995

1.5 Proceedings of IEEE 1997 Workshop on Accelerated Stress Testing

1.6 Schlagheck, J., *Environmental Stress Screening*

1.7 Tustin, W. and Mercado R., *Random Vibration in Perspective*

3.0 Background

Prior to the implementation of any stress screening equipment, the requirements for the screen and the constraints in the facility must be known. Very often, a balance between the most efficient screen and the limitations of the facility resources must be found.

The establishment of the screening parameter limits is documented during the Highly Accelerated Life Test (HALT). The HALT process is a discovery phase of testing during product development which uses environmental stimuli to:

1. Improve reliability (Mean-Time-Between-Failure, MTBF).

2. Determine operational and destruct limits.

3. Find opportunities to increase the margin between the product's guaranteed environmental specifications and the experimentally determined operational limits. Find opportunities to increase the margin between the product's experimentally determined operational limits and the experimentally determined destruct limits.

4. Learn about product failure behavior to help determine the best type of environmental stimuli which may be used during manufacturing screens.

After the operational and destruct limits are found, select a baseline screening profile that places the target stress levels between the operational limits and destruct limits. The ability to perform production screens at high stress levels allows the screening duration to be substantially reduced. After selecting the target stress screening profile parameters, an understanding of the capabilities of the facility which will house the screening equipment and the ability to upgrade the facility infrastructure to accommodate the screening equipment must be investigated. Areas of inquiry include:

1. Space availability, overhead clearances (determines size of chamber allowed)

2. Air supply including volume, pressure and cleanliness of the delivered air

3. Water supply

4. Liquid Nitrogen (LN2). Does the facility have an existing bulk resource?

5. Electricity, 208VAC 3 phase or 460VAC 3 phase

6. Proximity of facility resources with respect to the optimum placement of the screening equipment (i.e. placement of equipment in-line with remainder of the manufacturing process)

Upon assessment of facility capabilities, the choices for on-site screening equipment selection shall be evident.

4.0 Chamber design considerations for selection

Regardless of the chamber cooling technology chosen, all high performance chambers share the same characteristics to deliver the highest efficiency. One of the most important features in a chamber for high thermal rate changes is the airflow characteristics.

The most important aspects of airflow characteristics are volume (velocity), direction, airflow orientation within the product cavity and the plenum routing path. For fast thermal rate changes on the product, the need to move as many air molecules as possible across the product per unit time is paramount. Figure 1 below shows the affect of inadequate airflow characteristics. Although the chamber's heaters or evaporator coils are providing sufficient energy release (or absorption), the poor airflow prevents the product from responding to the temperature changes driven by the rest of the system. To direct airflow to a product (especially during a HALT process) a custom outlet duct adapter may be installed to reduce the cross sectional area of the outlet to the diameter of a 4 inch hose. The 4 inch hose is then installed and directed to a close proximity to the product under test. The purpose of this technique is to provide the fastest rate changes on the product and to direct airflow to product structures that would normally be in the shadow of the air stream. This technique should not be thought of as a remedy for poor airflow since the low volume of air across the heating or refrigeration coils still exists and contributes to poor efficiency. For mechanically cooled systems, significant airflow loss across the evaporator coil can result in damage to the compressor system. When the chamber has the correct amount of air flow, the product response will behave as shown in figure 2. A study performed by engineers at Hughes Aircraft showed that for thermal screening at greater than 10°C/minute, air-flow greater than 1,000 linear feet/minute was required.

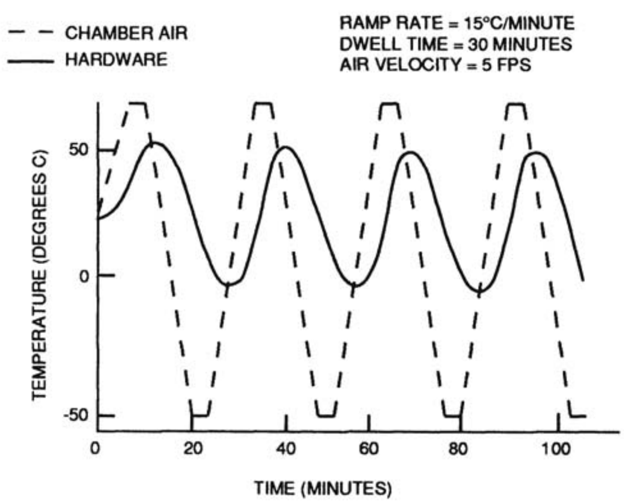

Figure 1 – Product response for the low airflow case

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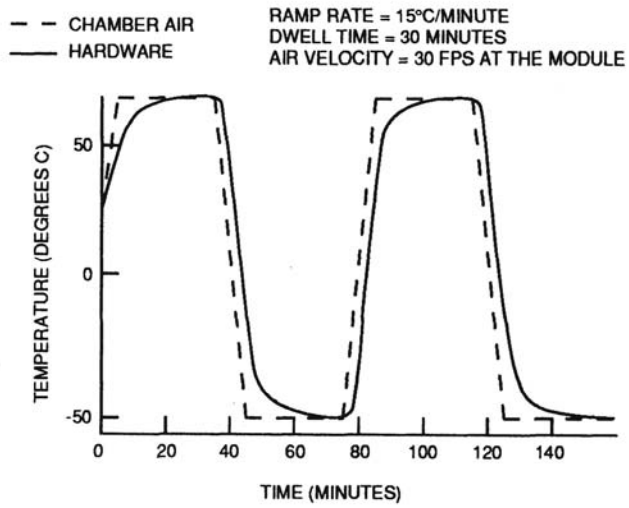

Figure 2 – Product response for the proper airflow case

In addition to adequate airflow velocity, airflow direction is important. The airflow direction in the chamber test cavity should be straight and travel from one side of the compartment to the opposite side of the compartment. The airflow can be horizontal or vertical airflow as long as the air is not required to make any 90° or 180° turns inside the test cavity.

Products inside the test cavity can represent a significant obstruction to air flow. While the velocity of the airflow can be high leaving the outlet duct, it can loose considerable speed after passing through layers of product. In addition, the affect of the temperature change on the products nearest the outlet duct will be considerably stronger than the products farthest from the outlet duct. The best chamber cavity design for airflow characteristic would be a cavity shaped like a narrow rectangle with the airflow traveling across the smallest dimension of the rectangle. In this scenario, products are arranged in a narrow column or row (depending on air flow direction) in a manner that airflow passes across only one layer of product.

The plenum routing path describes the movement of the air that is outside the product test cavity. In the plenum, the air will be required to make turns, pass though heating coils, evaporator coils and the circulation fan. Within the plenum, the chamber designer can implement the correct structures to guide the air in the most efficient manner. Figure 3 shows the basic path of airflow movement in a thermal chamber.

Thermal chambers are available using two basic fundamental designs: the single zone chamber and the multi-zone chamber. A diagram of a single zone chamber is shown in figure 3. Inside the chamber are the products to be screened, the chamber walls (liner), the heating coils, the circulation fan and the evaporator. All these elements constitute the load to the refrigeration system. For high performance compressors (30 hp), the evaporator alone will be a 100 lb mass of aluminum coils and fins. In some cases, the load contributed by the chamber components can exceed the load contributed by the product being screened. In chambers of this design, a single cascade 30 hp x 30 hp system should not be expected to perform cooling at rates much greater than 10°C/minute with an average product load. Certainly, extra compressors can be added to improve performance but the cost of the system and the cost to operate the system may become excessive.

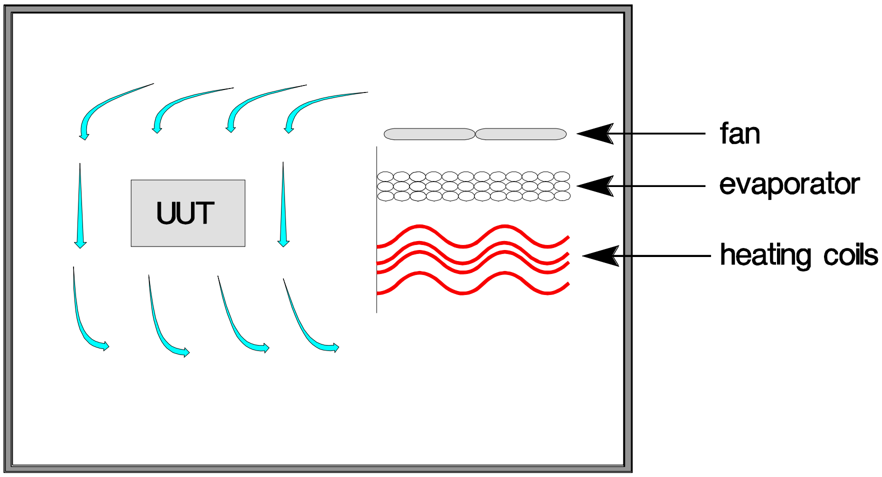

Figure 3 – Single zone chamber layout

An alternative to a single zone thermal cycling chamber is the use of a two zone chamber. Figure 4 shows an illustration of a two zone chamber. In this design, the chamber has one zone that is maintained at the hot temperature and the other zone maintained at the low temperature. In this arrangement, the product is moved between these two zones with the use of an elevator. When the product is transferred into the cold zone, the only load to the refrigeration is the floor and ceiling of the transfer basket along with the product being screened. Since the heavy evaporator coils are never heated, the evaporator coils do not contribute to the refrigeration load.

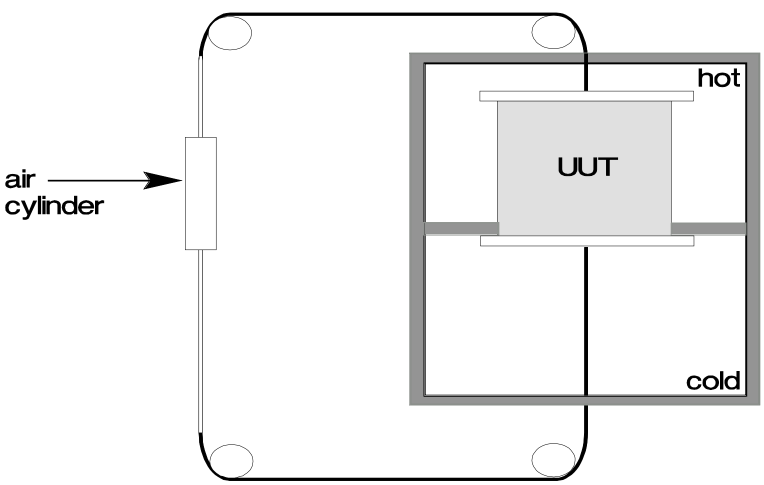

Figure 4 – Two zone air-to-air chamber

Multi-zone thermal chambers are more expensive than single zone chambers with the same heating and cooling system but an air-to-air chamber with a cascade 30hp x 30hp system can achieve rates of temperature change far exceeding 20°C/minute depending on the mass and composition of the product load. To provide more cooling capability to two zone chambers, a large cold sink (or cold storage) is usually added to the cold zone. The cold sinks are plates of aluminum that are pre-cooled in the cold zone to temperatures below the cold set point in the thermal profile. When the product basket transfers to the cold zone, the heat of the product is absorbed by the passive cold sinks while also being assisted actively by the mechanical refrigeration system. The effective cooling of this system will exceed the performance of the mechanical refrigeration alone. The air-to-air thermal chambers are the most efficient design of thermal chambers with mechanical refrigeration which can achieve high thermal rates of change.

The mechanical refrigeration systems consists of one of more compressors in a single stage or cascade configuration with either water cooled or air cooled condensers. The single stage compressor system allows cooling to about -20°C to -30°C. The cascade or dual stage compressor systems allow cooling to -70°C.

The choice of an air cooled or a water cooled condenser is largely determined by the size of the compressors. Small lab type systems with compressors under 5hp are generally air cooled (residential air conditioning systems are air cooled). High performance compressors that are greater than 5hp are generally water cooled. These systems can be air cooled but their efficiency can be impacted when the condenser is located at long distances from the chamber. Remote air cooled condensers also use more refrigerant than water cooled or internal air cooled condensers. A refrigerant leak in a remote air cooled condenser system will result in significantly more cost to recharge then the other condenser cooling technologies. Figure 5 shows the performance of the various sizes of cascade refrigeration systems.

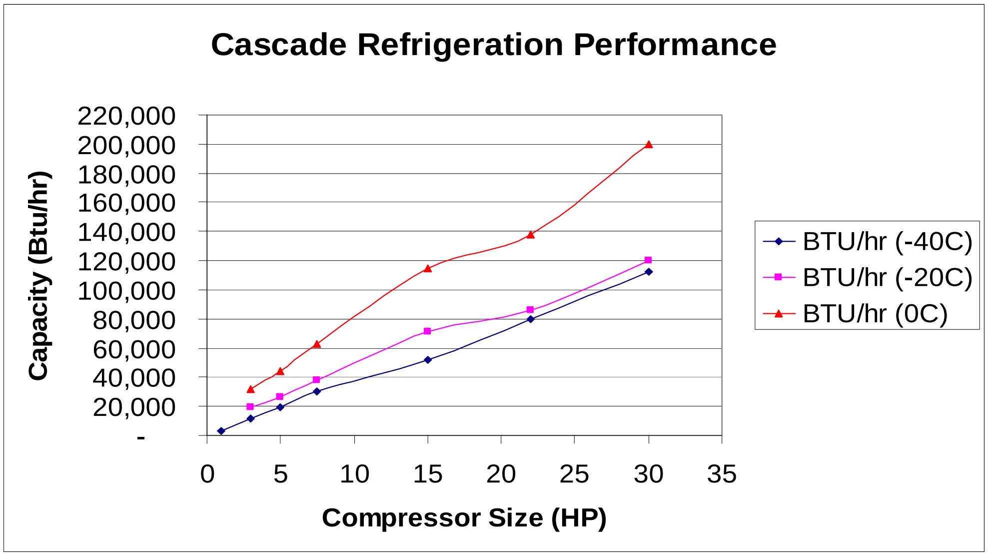

Figure 5 – Cascade Refrigeration Performance for various compressor sizes

The main disadvantage of the multi-zone chambers is the complexity of routing cables to products that need power applied for test monitoring and the inability to perform multi-stimulus screens such as thermal cycling with random vibration. In cases where fast thermal rate changes and vibration screening is required, the LN2 cooled system is the most capable technology. In an LN2 cooled system, the load to the cooling system is the product, the chamber walls (liner), the heating coils and the circulation fan. The lack of an evaporator substantially reduces the load for cooling and heating. In addition, an LN2 cooled system has cooling temperature slope characteristics that are more linear than mechanically refrigerated systems and the rate of cooling is more controllable without the thermal inertia caused by the heavy evaporator coil. Figure 6 below shows the capacity for cooling of LN2 for various screening minimum temperatures. Although the LN2 performance graph shows a linear relationship between screening temperature and nitrogen consumption, the actual performance at low temperatures is impacted by the BTU leakage of the chamber (see Appendix A, table 16). The higher BTU leakage at lower screening temperatures reduces the liquid nitrogen's effective performance in reducing the product temperature.

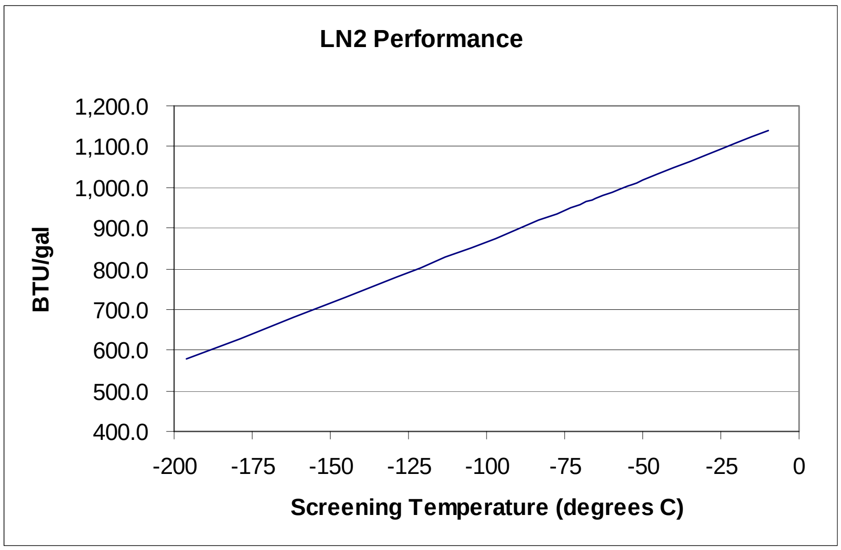

Figure 6 – LN2 Performance for various screening temperatures

For both mechanically cooled and LN2 cooled chambers, the heating systems are implemented in much the same manner. The heating coils in high performance chambers can exceed 90 KW in total energy output. Although the coils have the ability to contribute significantly to the chamber's energy level during heating, they do not contribute much of a load during cooling. Their light mass allows them to cool quickly to surrounding temperatures once the power to them has been switched off. Figure 7 shows the heating performance for several sizes of heating coils capacities.

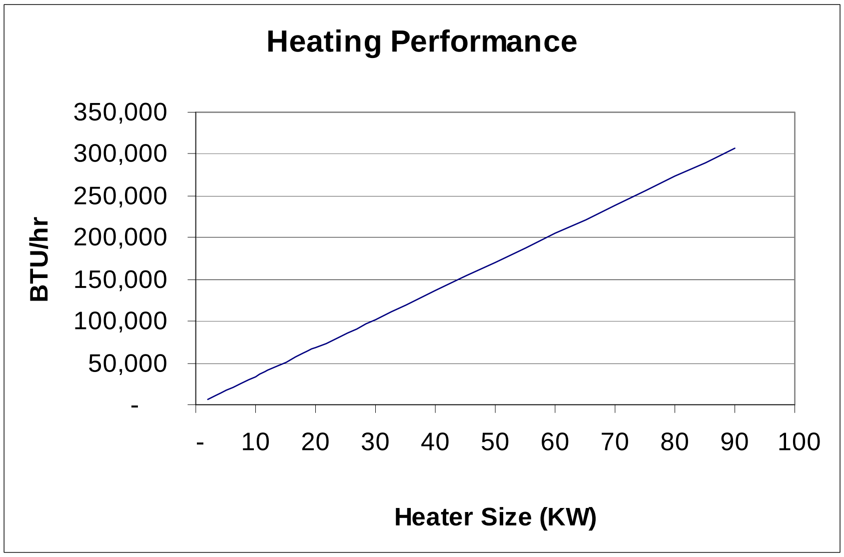

Figure 7 – Heating Performance for various heater sizes

Table 1 compares many of the characteristics of three high performance stress screening chamber technologies. The three technologies include a single zone dual cascade system, a dual zone single cascade system and a single zone LN2 system.

Table 1 – Chamber Technology Comparison

Chamber Technology	Dual Cascade Refrigeration, Single Zone Chamber	Single Cascade Refrigeration, Two Zone Chamber	LN2 Refrigeration, Single Zone Chamber
Cost of Equipment	High	High	Low
Maximum Rate of Change (°C/minute)	15	30	>40
Maintenance/Downtime	Highest	High	Low
Cost of use for fast thermal rate changes	High	Low	Low
Space requirements	High	High	Low
Electricity Consumption	High	Med	Low
Noise Level	High	High	Low
Multiple Stimuli (i.e. vibration)	Yes	No	Yes
Shop air requirements	Yes (dry air purge)	Yes (dry air purge)	No
Refrigeration performance affected by live loads?	Yes	Yes	No
Cooling water required	Yes 128 gpm	Yes 64 gpm	no

Unlike the LN2 refrigerated systems, the mechanically refrigerated systems are very sensitive to the heat dissipation of live loads. A live load is represented by a product under power dissipating heat into the chamber. As the mechanically refrigerated system is operating at 100% capacity, the extra heat load will slow the thermal cooling rate. An LN2 system is more immune to live loads since the extra load can be compensated by the dispensing of additional LN2. For most stress screening applications, the product should be un-powered during the cold ramp of the thermal profile to allow for the fastest possible ramp time. In addition, removing power from the product allows all the structures deep in the product to experience the same temperature as the surface. Depending on the rate of heat conduction in the product, a soak interval at each extreme in the profile is usually prescribed.

5.0 LN2 Facilities

If the stress screening system is required to use liquid nitrogen to perform the primary cooling function or to provide a boost capability to assist a mechanically refrigerated system, the implementation can take on many forms.

Liquid nitrogen can be supplied in three main packages: dewars, a large bulk tank or the newer micro-bulk tank. Dewars are small transportable containers that may be rented as part of the purchase of the LN2 product and come in 160 liter and 230 liter sizes. Dewars are usually placed close to the point of use and may feed into a manifold so multiple dewars can be used during times of unattended LN2 consumption without exhausting the LN2 resource. The dewar system represents the most costly scenario for the use of LN2.

Large bulk tanks, as the name implies, are substantial reservoirs of LN2 storage. These systems can be made very large to hold quantities in excess of 5000 gallons. The large bulk tanks, due to their size, are found outside of facilities and are plumbed into the building in a vacuum jacketed pipe to the location of consumption. The installation of a bulk tank is costly and requires special safety considerations especially in active seismic regions. The large bulk tank, overall, is the least costly method to store and distribute liquid nitrogen.

A newer system that has most of the advantages of the dewar and the large bulk tanks is the micro-bulk system. A micro-bulk is a small storage container for liquid nitrogen that lies between the size of the dewar and the large bulk tanks. The micro-bulk can be placed inside a facility and plumbed over short distances to the point of use. The microbulk enjoys the economies of volume purchases and can be filled from the outside of the facility. Table 2 below compares the merits of each system. More information about Micro-Bulk storage options can be found in Appendix C table 18.

Table 2 – LN2 storage options

	Dewar	Micro-Bulk	Large-Bulk
Cost for nitrogen	Highest	Medium	Lowest
Cost of installation	Lowest	Medium	Highest
Nitrogen Loss per day	3-5%	< 1%	<1%
Remote fill	N/A	Yes	Yes
Wasted product (container returned to supplier not empty)	Yes	No	No
Fill time/delivery time	Slow	Fast (2-12 minutes)	Fast (determined by tank size)
Fill while in use	No	Yes	Yes
Telemetry System (for auto replenishment)	No	Yes	Yes
Inside facility use	Yes	Yes	No
Need to transport	Yes	No	No

The choice of storage will determine the nature and complexity of the remainder of the installation. For thermal chambers that require < 10 gallons of LN2 to bring the chamber to the lowest selected temperature, the delivery system for all storage methods have many of the same characteristics for the best overall performance. The first and primary consideration is the delivery of the LN2 to the chamber while it is still in liquid phase. The cooling properties of LN2 come from the liquid to gas phase change and the super heating of the nitrogen gas. The phase change of nitrogen occurs at -196°C and consumes 577 BTUs per gallon of liquid nitrogen. The heating of the cold gaseous nitrogen from -196°C to -40°C will consume another 471.5 BTU per gallon of the original liquid nitrogen. The significance of maintaining LN2 in the liquid phase until it enters the chamber should be clear. More guidelines for the implementation of a liquid nitrogen delivery system are outlined below:

1. Use rigid vacuum jacketed pipe as much as possible. VJ pipe is more efficient than flexible VJ pipe. Do not use un-insulated steel braided hose pipe except for very short runs (< 4 feet).

2. Minimize the number of couplings in the distribution system. The couplings do not have vacuum insulation. Insulate all permanent couplings with external foam insulation. Tape all ends to maintain a seal to water vapor. (water conducts heat much more effectively than air)

3. Keep the length of the vacuum jacketed system to a minimum. During times of no LN2 demand, the LN2 in the line will eventually warm up and undergo a phase change.

4. Use small diameter pipe for the innermost sleeve (< ½ inch). Small diameter pipe allows for the minimum volume of gaseous nitrogen in the pipe that will require purging when the chamber starts a cooling ramp. Fast purge times allow the chamber to receive nitrogen in the liquid phase soon after the demand starts.

5. Set the LN2 pressure to 35-50 psi. Along with the potential long runs and nitrogen gas in the line, the higher pressure will allow liquid nitrogen to be delivered in the desired volumes and in the shortest time for the fastest thermal rate changes.

6. Vent inside plant nitrogen containers to the outside. All nitrogen containers are required to vent the excess nitrogen pressure for safety. The higher pressure systems can vent significant volumes of gaseous nitrogen when there is no demand. Install a vent hood or a vent hose to dissipate the nitrogen outside the plant. Have an oxygen sensor near the chamber and in-plant nitrogen reservoir to protect personnel.

7. Make sure the chamber doors and cable ports plugs seal well to prevent gaseous nitrogen from escaping into the room from the chamber or to prevent moisture in the room from entering the chamber.

8. Make sure the chamber nitrogen vent is not blocked and easily allows the gaseous nitrogen to escape from the chamber. Make sure the chamber vent is plumbed to the outside of the facility.

6.0 Chamber Performance Calculation

The example below will be used to demonstrate the method to calculate the maximum performance for a chamber with a given load. In the example, the maximum heating rate of change and the number of gallons of LN2 that will be consumed during the screen will be determined. All the input information is provided below.

Table 3 - Screening Parameters

Parameter	Value
Temperature Range	-55 ºC to +65 ºC
Desired Ramp Rate	40ºC/minute
Dwell or Soak Time	15 minutes at each extreme
Total Number of Cycles	10

Table 4 - Product and Fixturing

Parameter	Weight (lbs)	Specific Heat (BTU/ lb ºC)
Product material composition by weight		
25% Aluminum	5	0.41
25% IC packages	5	1.57
50% PCB material	10	0.72
Fixturing (aluminum)	5	0.41

See appendix B table 17 for specific heats of common materials

Table 5 – Parameters for Screening Systems QRS-410 chamber

Parameter	Value
Cooling Method	LN2
Heater Size (see figure 7)	18 KW (61,416 BTU/hr)
System Factor (system heat load)	49 BTU/ ºC
Holding Leakage @ -55 ºC (approx)	334 BTU/hr

See appendix A tables 15 for system factors of common LN2 cooled stress screening equipment and table 16 for holding BTU leakage for the QRS-410 system

First calculate the total loads and represent them as BTU/ ºC. The load value for the product will be the mass of each product constituent multiplied by the specific heat of the material.

Table 6 – Load values for product and fixturing

Load	Weight (lbs)	Specific Heat (BTU/ lb ºC)	Load Value (BTU/ºC)
Product 25% Aluminum	5	0.41	2.05
Product 25% IC packages	5	1.57	7.85
Product 50% PCB material	10	0.72	7.2
Fixturing (aluminum)	5	0.41	2.05
Chamber System Factor			49
		Total	**68.15**

The next step is to determine the total number of BTU's that will be required to change the product temperature by 120ºC as specified in the input information.

The total load is 68.15 BTU/ºC.

The number of BTU's required to change the temperature by 120 ºC

= 68.15 BTU/ºC x 120 ºC

= 8,178 BTU

The heating rate of change is given by:

(BTU) x (60 min/hr) x (temp change ºC/min) x 1/(temp range ºC) = heat capacity BTU/hr

8,178 BTU x 60 min/hr x (temp change ºC/min) x 1/120 ºC = 61,416 BTU/hr

Temp change = 15.02 ºC/min

The best case temperature rate of change is much less than the desired 40 ºC/min.

To achieve a 40 ºC/min rate change, the heater size would need to be:

8,178 BTU x 60 min/hr x 40 ºC/min x 1/120 ºC = **163,560 BTU/hr (48 KW)** - see fig. 7

Now calculate the liquid nitrogen consumption for the screen. Using figure 6, the cooling performance of liquid nitrogen at -55 ºC is 1003.3 BTU/gal.

The equation to calculate the amount of LN2 to decrease the temperature by 120 ºC is:

8,178 BTU / 1003.3 BTU/gal = **8.15 gallons of LN2**

Now calculate the consumption of LN2 for the 15 minute cold dwell (soak) in the stress screen profile. The chamber holding leakage is 344 BTU/hr at -55 ºC. Since the cold soak dwell time is 15 minutes, the number of BTU's to hold the temperature for 15 minutes at -55 ºC is:

344 BTU/hr x 15 min. x 1 hr/60 min. = 86 BTU

The quantity of LN2 needed is:

86 BTU / 1003.3 BTU/gal = **0.09 gallons**

Per cycle, the amount of LN2 needed is 8.15 gallons + 0.09 gallons = **8.24 gallons**

For the 10 cycle screen, the amount of LN2 needed is **82.4 gallons**.

Note: this example neglects and LN2 consumption during the heating cycles maintain set point.

7.0 Chamber use Model Comparisons

Using figure 8 below, several examples of potential chamber implementations will be modeled to show capability and approximate cost of use. Each chamber technology provides different maximum rates of thermal changes. The thermal chambers compared will be the single zone dual cascade system at 15°C/minute, the dual zone single cascade system at 30°C/minute and the single zone LN2 system at 40°C/minute. On figure 8, the dark line associated with surface mount field returns will be used to map a given rate of thermal change to the number of stress screening cycles that will be needed.

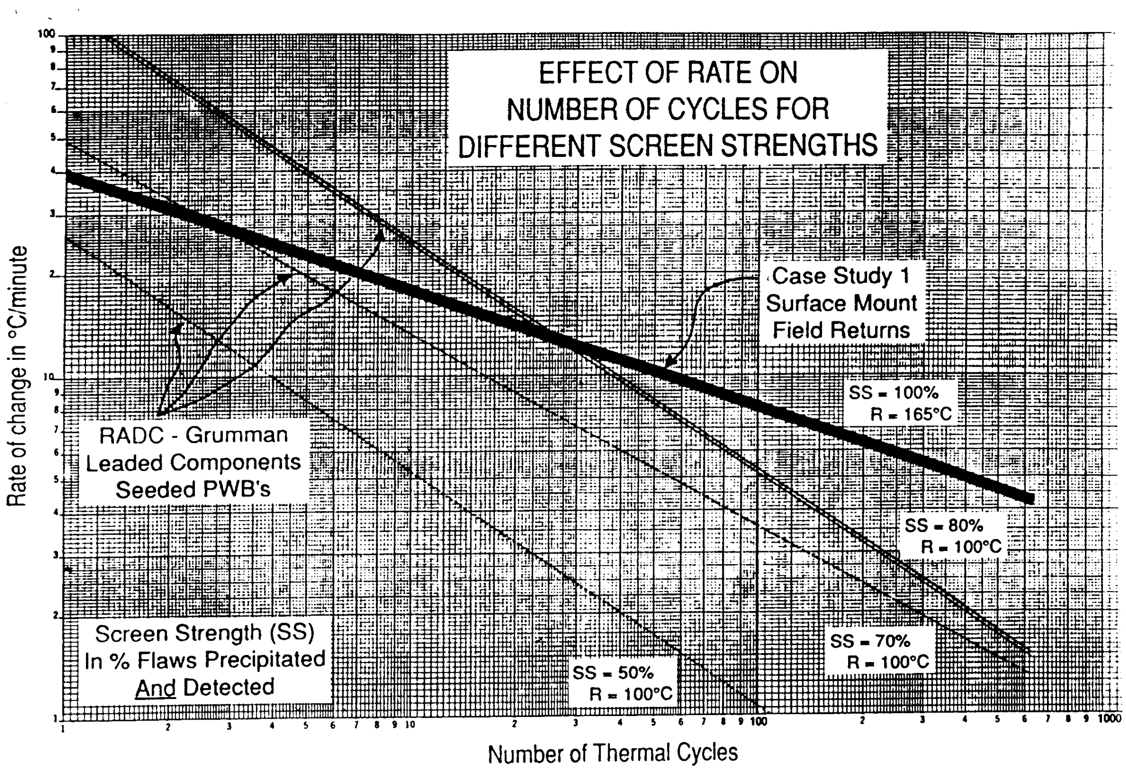

Figure 8 – Number of thermal cycles as a function of rate of temperature change

For the three chamber technologies, the chamber technology type, the maximum rate of change and the required number of thermal cycles are shown in table 7 below.

Table 7 – Three stress screening scenarios

Chamber Technology	Thermal Rate of Change (°C/minute)	Number of Required Thermal Cycles
Dual Cascade Single Zone Chamber	15	20
Single Cascade Two Zone Chamber	30	3
LN2 Cooled Single Zone Chamber	40	1

All three examples will share the base parameters shown in table 8. To simplify the analysis for comparative purposes, the fixture load and unload time, fixturing weight and dwell time will be set to zero. The cost of the cooling water for the mechanically cooled chambers will also be neglected.

Table 8 – Base parameters for stress screen technology comparison

Parameter	Value
Product weight	Equivalent heat capability of 1 lb of aluminum
Product volume	0.0463 ft^3 (2” x 5” x 8”)
Powering State	Non powered (dead load)
Number of Products to be screened per day	250
Number of production hours per day	16
Load/Unload Time	0 hours
Fixturing Weight	0 lbs.
Temperature Range	-40°C to +80°C
Soak Time	0 minutes at each extreme
Excess Chamber Volume	Allow product to consume up to 2/3 of chamber volume (to allow for airflow around the product)

Table 9 - Case 1: Dual Cascade Single Zone Chamber

Parameter	Value
Thermal Rate of Change	15°C/minute
Number of Cycles	20
Soak time at each extreme	15 minutes
Minutes/Cycle	46
Minutes/Screen	920
Screens per day	1
Products per screen	250
Weight of Products	250 lbs
Total Product Volume	11.58 ft^3
Required Chamber Volume	17.4 ft^3
Total Product Heat Load (see appendix A), Heat load = Weight x Specific heat of aluminum	102.5 BTU/°C
Chamber Heat Load (approximate)	54 BTU/°C
Evaporator Coil Heat Load (approximate)	82 BTU/°C
Total Heat Load	238.5 BTU/°C
For 120°C temperature excursion, the number of BTU's required	28,620 BTU
For an 8 minute ramp, this is the resource capacity needed	214,650 BTU-hr
Heating Capacity Required	63 KW
Cooling Capacity Required (from figure 5)	Dual 30hp x 30hp
Estimated Energy Consumption Heater = 63 KW, used 25% of time = 15.75 KW Compressors = 89.5 KW used 25% of time = 22.38 KW Blowers 2 @ 5hp = 7.5 KW Total of 3 Cooling Tower Motors 20hp = 15 KW Total = 60.63 KW x 0.15 $/KW-hr x 15.33hrs	139.42 $/screen 139.42 $/day

Table 10 - Case 2: Single Cascade Dual Zone Chamber

Parameter	Value
Thermal Rate of Change	30°C/minute
Number of Cycles	3
Soak time at each extreme	15 minutes
Minutes/Cycle	38
Minutes/Screen	114
Screens per day	8
Average Products per screen	31.25
Average Weight of Products	31.25 lbs
Total Product Volume	1.45 ft^3
Required Chamber Volume	2.16 ft^3
Total Product Heat Load (see appendix A), Heat load = Weight x Specific heat of aluminum	12.8 BTU/°C
Chamber Heat Load	9 BTU/°C
Evaporator Coil Heat Load (approximate)	N/A
Total Heat Load	21.8 BTU/°C
For 120°C temperature excursion, the number of BTU's required	2,616 BTU
For a 4 minute ramp, this is the resource capacity needed	39,240 BTU-hr
Heating Capacity Required	11.5 KW
Cooling Capacity Required (from figure 5)	Single 12hp x 12hp (use 15hp x 15hp)
Estimated Energy Consumption Heater = 11.5 KW, used 100% of time (with pre-heating) Compressors = 22.4 KW used 100% of time (with pre-cooling) Blowers 2 @ 1hp = 1.5 KW Total of Cooling Tower Motors 15hp = 11.2 KW Total = 46.6 KW x 0.15 $/KW-hr x 1.9hrs	13.28 $/screen 106.24 $/day

Table 11 - Case 3: LN2 Cooled Single Zone Chamber

Parameter	Value
Thermal Rate of Change	40°C/minute
Number of Cycles	1
Soak time at each extreme	15 minutes
Minutes/Cycle	36
Minutes/Screen	36
Screens per day	26
Average Products per screen	9.6
Average Weight of Products	9.6 lbs
Total Product Volume	.44 ft^3
Required Chamber Volume	0.66 ft^3
Total Product Heat Load (see appendix A), Heat load = Weight x Specific heat of aluminum	3.9 BTU/°C
Chamber Heat Load	18 BTU/°C
Evaporator Coil Heat Load (approximate)	N/A
Total Heat Load	21.9 BTU/°C
For 120°C temperature excursion, the number of BTU's required	2,628 BTU
For a 3 minute ramp, this is the resource capacity needed	52,560 BTU-hr
Heating Capacity Required	15.4 KW
LN2 Required (using figure 6)	2.5 gallons
Estimated Resource Consumption Heater = 15.4 KW, used 10% of time = 1.54 KW Blowers 1hp = 0.75 KW 2.5 gallons of LN2 @ 1.50 $/gallon = $3.75 Total = 2.29 KW x 0.15 $/KW-hr x 0.6hrs + 3.75	3.95 $/screen 102.7 $/day

Table 12 – Three stress screening scenarios with results compared

Chamber Technology	Thermal Rate of Change (°C/minute)	Number of Thermal Cycles Required	Cost per day (relative)
Dual Cascade Single Zone Chamber	15	20	$135.42
Single Cascade Two Zone Chamber	30	3	$106.24
LN2 Cooled Single Zone Chamber	40	1	$102.7

8.0 Summary and Conclusion

The HALT process will provide a set of target stress screening parameters for the production level stress screen. Equipment choices will affect stress screening performance in regards to the number of cycles required to perform the screen. Available resources in a facility can have a profound affect on the choice of stress screening equipment.

The choices available for high performance thermal stress screening equipment are a single zone dual cascade chamber, a dual zone single cascade chamber and a single zone LN2 cooled chamber. For ultra fast rate changes with an additional stimulus such as random vibration, the only capable choice available is a single zone LN2 cooled chamber.

The chamber capabilities in terms of heating and mechanical cooling are limited resources. Excessive load in the chamber will have a pronounced affect on the thermal change rates and overall screen duration. Generally, is it more cost effective to reduce the number of products in each screen and perform more screens per day than using a larger chamber with a heavier product load.

Appendix A

Table 13 - Mechanical Refrigeration Coil loads:

Refrigeration Type	Btu/hp
R-13, R-23	0.75
R-404, R-502	0.90
R-12, R-134	1.00

Table 14 - Chamber Liner and Box Loads:

Chamber Type	Liner BTU/ft^2	Box BTU/ft^2
AGREE	0.30	0.26
Altitude	0.95	0.40
Walk-in	0.17	0.40

Table 15 - System Factors for HALT/HASS Chambers:

Chamber Manufacturer	Chamber Model	System Factor (BTU/°C)
Qualmark	OVS-1	18
Screening Systems	QRS-400/410T	49
Qualmark	OVS-2	54
Qualmark	OVS-2.5	54
Qualmark	OVS-3U	81
Qualmark	OVS-3L	99
Qualmark	OVS-4U	126
Qualmark	OVS-4L	148

Table 16 - Holding BTU leakage for QRS400/410T chambers

Holding Temperature (°C)	BTU leakage (BTU/hr)
10	67
0	108
-10	149
-20	190
-30	232
-40	273
-50	314
-60	355

Appendix B

Table 17 - Specific Heats of Common Materials:

Material	Specific Heat (BTU/lb/°C)
Aluminum	0.41
FR4 (PCB material)	0.72
Carbon Steels	0.20
Molded Epoxy (IC packages)	1.57
300 Series Stainless Steel	0.22
Teflon	0.45
Delrin	0.63
Air	0.032

Appendix C

Table 18 - Microbulk Model Specifications

Model	230BMP	230CMP	450MP	450HP	1000MP	1000HP	1500HP
Gross Capacity (liters)	240	240	450	450	1,056	1,056	1,550
Net Capacity (liters)	230	230	420	420	950	950	1,455
NAWP (psig)	250	235	250	350	250	350	350
Max Gas Delivery Rate (scf/h)	400	400	575	575	960	960	1,350
Diameter (in)	26	26	30	30	42	42	48
Height (in)	61	54.8	68	68	77	77	91
Tare Weight (lb)	340	300	605	668	1,550	1,750	2,692
Design Specifications	ASME	DOT	ASME	ASME	ASME	ASME	ASME
Materials of Construction	Inner and Outer Shell 304 Stainless						