What is Environmental Testing? Part 3

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Automotive electronics technology has been making astounding progress in recent years, and other types of mobile equipment, such as portable telephones and notebook computers, have become remarkably popular. Along with this, high-tech explosion has come a corresponding increase in the severity of the environments in which such equipment and parts are used, requiring much higher quality, and bringing much greater concern for safety and reliability. This combination of factors has prompted much greater interest in more severe testing such as "Thermal Shock Testing" and "Combined Environmental Testing".

In the past two issues we have attempted to explain "Environmental Testing" in our series with Part 1 on "Temperature Testing" and Part 2 on "Humidity Testing". In this article, the third and last in the series, we shall discuss "Thermal Shock Testing" and "Combined Environmental Testing".

Contents

*1 Overseas Business Department
*2 Combined Environmental Test System Project

1. Thermal Shock Testing

1-1 Summary of Testing

As we mentioned at the beginning of this article, the level of reliability required for these products necessitates particularly severe testing. We would like to present the following reasons for that necessity.

- The miniaturization of parts and equipment makes items particularly susceptible to heat.
- Production processes may inflict serious heat stress, e.g., when reflow soldering.
- Parts receive increasingly greater heat stress due to higher product precision.
- The usage environment has become much harsher with the expansion of the automotive electronics field.
- Reliability requirements have become much more severe day by day.

In America, Thermal Shock Testing is often performed for 100 percent inspection before shipping as a form of screening. In Japan, Accelerated Testing is often performed as one aspect of reliability testing as a step in the development process. In either case, this testing aims to observe changes in characteristics as well as changes in failure occurrence caused by the differing coefficients of thermal expansion for the materials composing the parts. These changes are observed by exposing parts alternately to extremes of high and low temperatures.

Such applications form the basis for the increasingly crucial role Thermal Shock Testing is seen to play.

In actual processes such as during production and when actually using the product, thermal shock occurs in the following types of cases, which are often related to equipment failure.

1) Extreme rises in temperature may occur in reflow soldering processes.
2) Extreme rises in temperature of peripheral parts may occur when starting the engine, and in cold regions an extreme drop in temperature may follow stopping the engine.
3) Equipment may be carried from inside a warm room to cold outdoor temperatures, or from cold outdoor temperatures to warm indoor temperatures.
4) Equipment may be connected to the power source in a cold environment, resulting in a precipitous temperature gradient in the internal parts of the equipment. Disconnecting the power source in a cold environment may result in a precipitous temperature gradient in the opposite direction.
5) Equipment may be cooled abruptly by rainfall.
6) Equipment attached externally to aircraft may encounter abrupt temperature changes as the aircraft goes up to or comes down from high altitudes.

1-2 Examples of Failure Caused by Thermal Shock

We would like to present three examples of failure caused by thermal shock of commonly used electronic parts.

<Presentation: Chubu Electronics Development Association, “Study on Reliability of Printed Circuit Boards (sixth), — on Efficient Conditions of Thermal Shock Test. —”>

Example 1

Photos 1 and 2 show the section of the connector pin that has been dislocated. Due to the difference in the glass epoxy printed board (coefficient of thermal expansion: 3.7×10^{-5}) and the connector resin (coefficient of thermal expansion: 7.2×10^{-5}) to which the connector pin is attached, upward and downward forces are applied to the solder jointing by thermal shock, promoting solder cracking and connector pin dislocation.

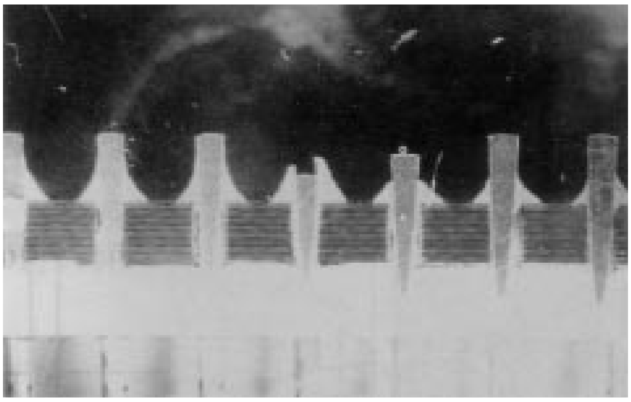

Photo. 1 Cross section of area with dislocated connector pin

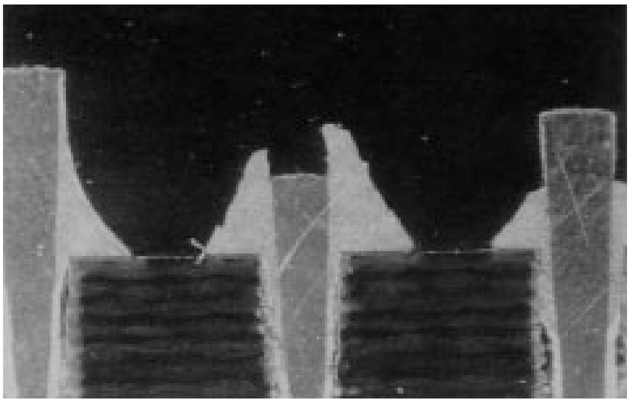

Photo. 2 Enlargement of cross section of area with dislocated connector pin

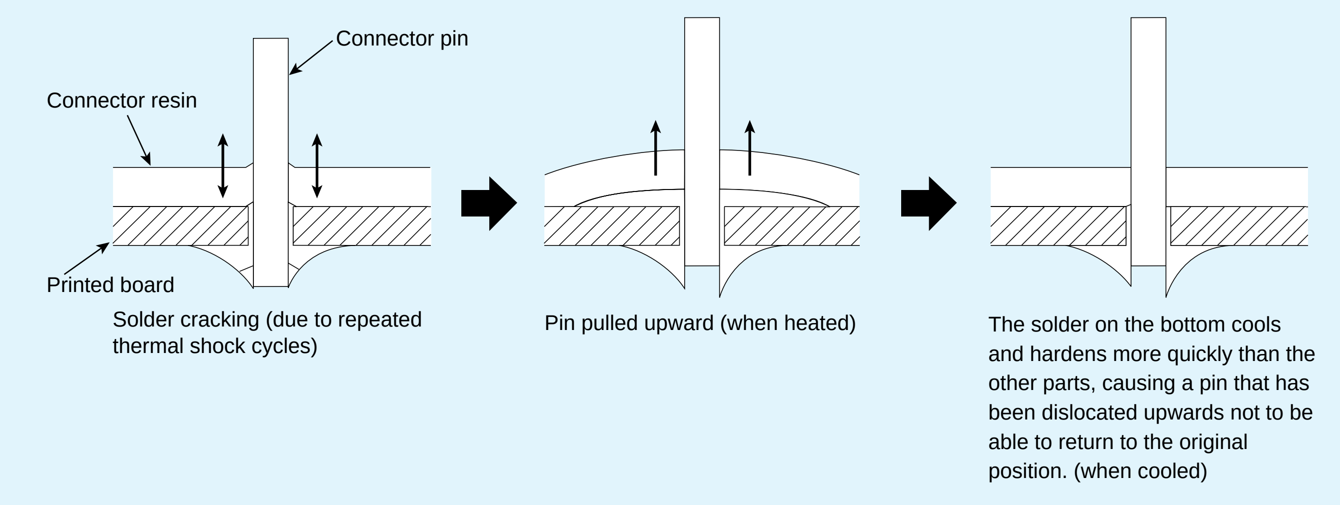

Fig. 1 Pin dislocation mechanism (hypothetical)

Example 2

Fig. 2 shows the internal composition of a resistance array. This resistance array has 8 components inside a single DIP package. Photo. 3 shows a normal resistance film, but Photos 4 through 7 show resistance array sections with resistance values increased or with infinite values, caused by thermal shock. All of these resistance films have been peeled from alumina substrate boards. When these receive thermal shock, the difference in coefficients of thermal expansion among the protective resin, resistance film, and the alumina substrate board causes repeated internal stress, and promotes resistance film cracking and peeling from the alumina substrate board.

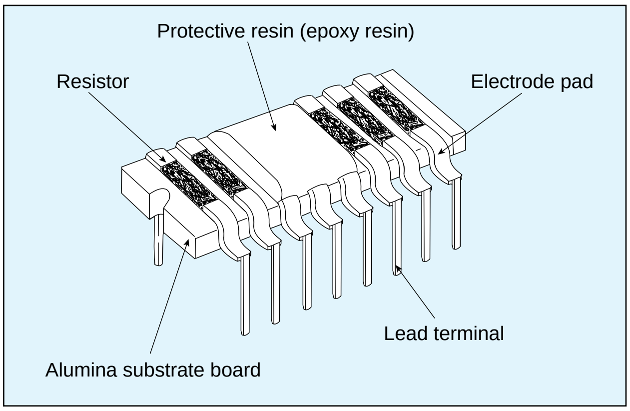

Fig. 2 Internal composition of the resistance array

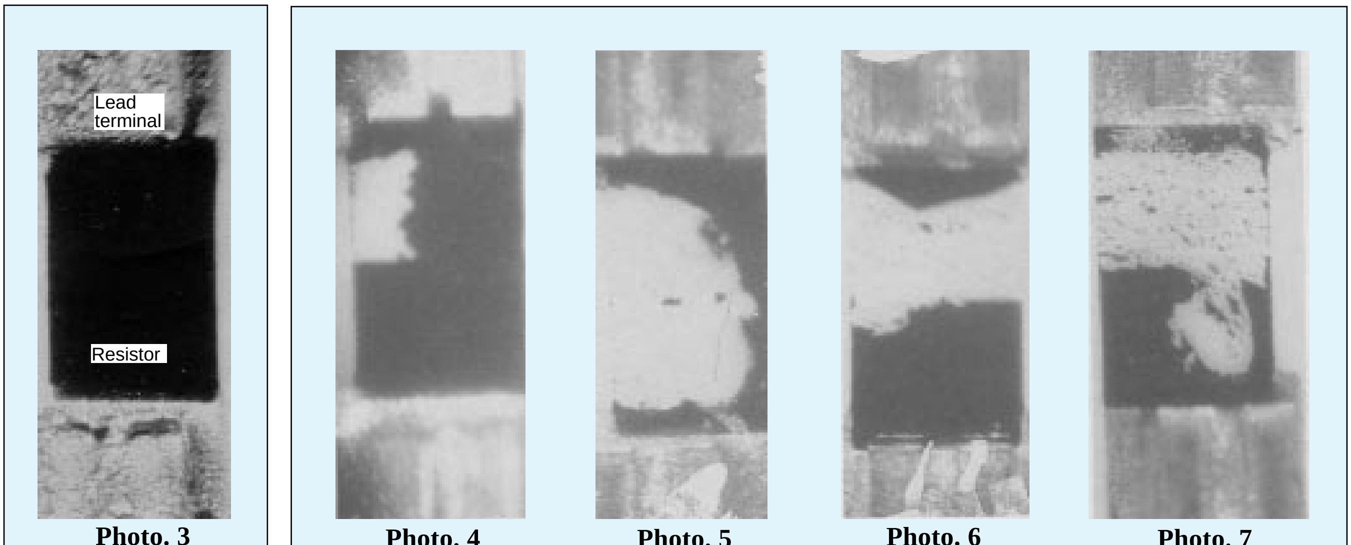

Photo. 3 (1kΩ) **Photo. 4 (1.3kΩ)** **Photo. 5 (3.4kΩ)** **Photo. 6 (∞Ω)** **Photo. 7 (∞Ω)**

Values in ( ) show resistance value.

Normal resistance film **Resistance film exhibiting peeling**

Example 3

Fig. 3 shows the composition of an LED bicolored light. In Photo. 8, both bonding Au wires are broken near the tip due to thermal shock. This is due to the differences in the coefficients of heat expansion for the tip, lead, and mold causing internal stress at the interface between the lead and the mold, and the interface between the tip and the mold. Such stress causes cracking and peeling and promotes breaking of the bonding Au wire.

These failures, peeling and by broken wires, have been caused by the physical force produced by the differences in coefficients of thermal expansion.

In America, the purpose for using Thermal Shock Testing for screening electronics parts is to discover defects before shipping. When design defects or manufacturing defects exist, the physical force applied by the Thermal Shock Testing finds the defects.

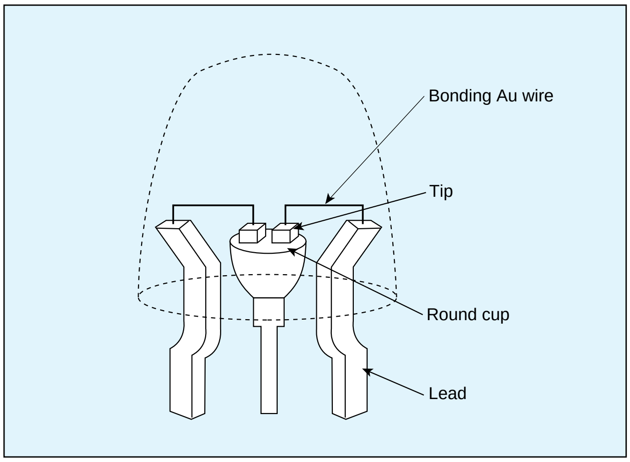

Fig. 3 Composition of LED bicolored light

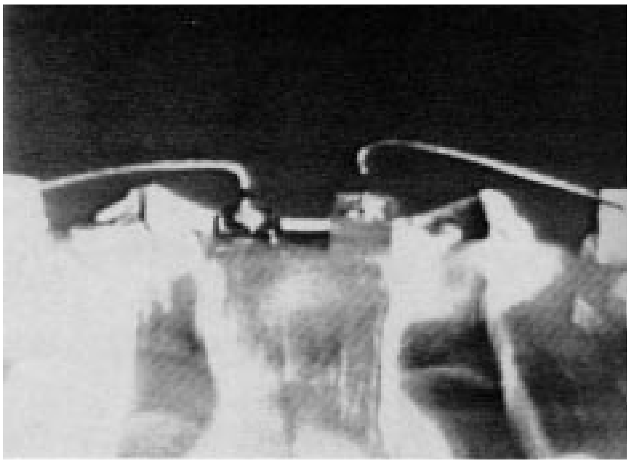

Photo. 8 Cross section region of broken wire

1-3 Types of Thermal Shock Testing

Thermal Shock Testing can be divided into two main types. One type consists of an air chamber in which the specimen is alternately exposed to hot air and cold air. The other type consists of a liquid bath in which the specimen is alternately exposed to a hot liquid and a cold liquid.

Since the liquid in which the specimen is soaked in the liquid bath method has much greater heat capacity than air, the temperature of the specimen can be changed much more abruptly than with the air chamber method. Because of this, failures may appear in the liquid bath method that have not shown up in the air chamber method, and failures tend to appear earlier.

Fig. 4 shows changes in conductor resistance on Printed Wiring Boards (herein after called PWBs) caused by the air chamber method and by the liquid bath method. This graph indicates that the liquid bath method causes changes in characteristics at fewer cycles. (Details for the graph are given in “Report 1” of Technology Report No. 3.)

In addition, even supposing that failures were to occur at the same number of cycles in both the air chamber method and the liquid bath method, equivalent cycle time is much shorter in the liquid bath method. For example, in the MIL-STD-202F that we shall talk about later, when a specimen weighs 100 grams, exposure for 30 minutes in the air chamber method would equal exposure for 5 minutes in the liquid bath method, that is, results can be obtained in one-sixth the testing time. However, drawbacks for the liquid bath method include the extremely high cost of the liquid medium used in the bath, as well as such troubles as handling the liquid and cleaning the specimens after testing.

The air chamber method includes both the two zone method, repeatedly alternating between high and low temperatures, and the three zone method, repeatedly cycling from high to normal to low temperature and back again. The two zone method is the more severe of these, as it produces much more precipitous temperature changes.

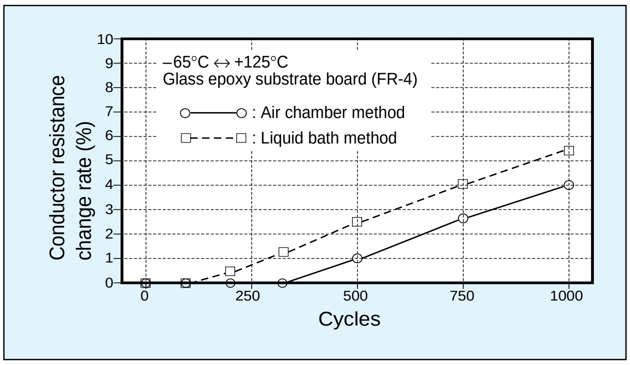

Fig. 4 Changes in conductor resistance due to the air chamber method and the liquid bath method

1-4 Principal Standards for Thermal Shock Testing

1-4-1 Names of Thermal Shock Tests

Names of “Thermal Shock Tests” differ according to the standards used, so they must be properly identified. Listed below are the names for the major standards. In this article we will consolidate them as “Thermal Shock Testing”.

MIL-STD-202F (air chamber method)	Thermal shock
MIL-STD-202F (liquid bath method)	Thermal shock
MIL-STD-810E (air chamber method)	Temperature shock
MIL-STD-883D (air chamber method)	Temperature cycling
MIL-STD-883D (liquid bath method)	Thermal shock
IEC-Pub.68-2-14 (air chamber method)	Change of temperature
IEC-Pub.68-2-14 (liquid bath method)	Change of temperature

1-4-2 MIL-STD-202F Test Methods for Electronic and Electrical Component Parts

Test Method: 107G Thermal shock

(1) Air chamber method test conditions

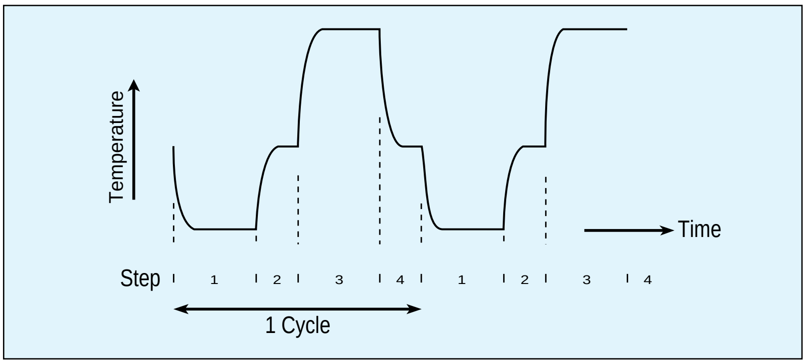

Fig. 5 Test pattern of air chamber method

Table 1 Thermal shock testing conditions (air)

Step	**Test condition**	**Number of cycles**	**Test condition**	**Number of cycles**	**Test condition**	**Number of cycles**
	A	5	**B**	5	**C**	5
	A-1	25	**B-1**	25	**C-1**	25
	A-2	50	**B-2**	50	**C-2**	50
	A-3	100	**B-3**	100	**C-3**	100
	Temperature (˚C)	**Time**	**Temperature (˚C)**	**Time**	**Temperature (˚C)**	**Time**
1	-55^{+0}_{-3}	See table 2	-55^{+0}_{-5}	See table 2	-65^{+0}_{-5}	See table 2
2	25^{+10}_{-5}	5 minutes max.	25^{+10}_{-5}	5 minutes max.	25^{+10}_{-5}	5 minutes max.
3	85^{+3}_{-0}	See table 2	125^{+3}_{-0}	See table 2	200^{+5}_{-0}	See table 2
4	25^{+10}_{-5}	5 minutes max.	25^{+10}_{-5}	5 minutes max.	25^{+10}_{-5}	5 minutes max.

Step	**Test condition**	**Number of cycles**	**Test condition**	**Number of cycles**	**Test condition**	**Number of cycles**
	D	5	**E**	5	**F**	5
	D-1	25	**E-1**	25	**F-1**	25
	D-2	50	**E-2**	50	**F-2**	50
	D-3	100	**E-3**	100	**F-3**	100
	Temperature (˚C)	**Time**	**Temperature (˚C)**	**Time**	**Temperature (˚C)**	**Time**
1	-65^{+0}_{-5}	See table 2	-65^{+0}_{-5}	See table 2	-65^{+0}_{-5}	See table 2
2	25^{+10}_{-5}	5 minutes max.	25^{+10}_{-5}	5 minutes max.	25^{+10}_{-5}	5 minutes max.
3	350^{+5}_{-0}	See table 2	500^{+5}_{-0}	See table 2	150^{+3}_{-0}	See table 2
4	25^{+10}_{-5}	5 minutes max.	25^{+10}_{-5}	5 minutes max.	25^{+10}_{-5}	5 minutes max.

Table 2 Exposure time in air at temperature extremes

Weight of specimen	**Minimum time (for steps 1 and 3): Hours**
1 ounce (28 grams) and below	1/4 (or as specified)
Above 1 ounce (28 grams) to 0.3 pound (136 grams), inclusive	1/2
Above 0.3 pound (136 grams) to 3 pounds (1.36 kilograms), inclusive	1
Above 3 pounds (1.36 kilograms) to 30 pounds (13.6 kilograms), inclusive	2
Above 30 pounds (13.6 kilograms) to 300 pounds (136 kilograms), inclusive	4
Above 300 pounds (136 kilograms)	8

The special features of this standard are as follows.
a) Either the one or two chamber method can be used, but normal temperature exposure is not suited to the single chamber method.
b) Exposure (dwell) time has been clearly determined according to specimen weight.
c) Prescribed temperature can be reached within 5 minutes after moving the specimen.
d) Specimens can be transferred within 5 minutes.
e) Specimens must not be put directly in the path of forced circulation air while they are being moved.

(2) Liquid bath method conditions

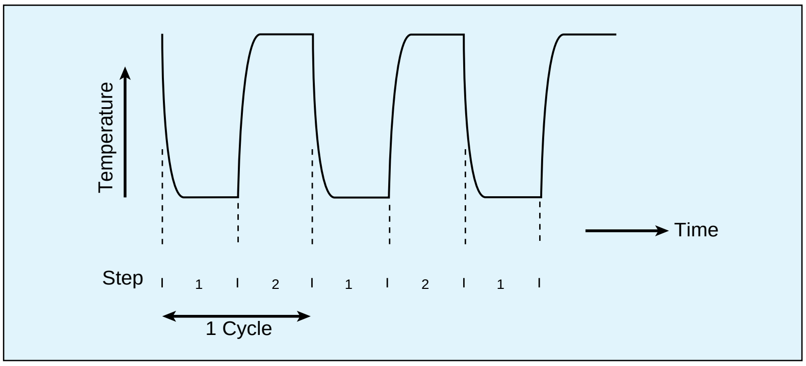

Fig. 6 Test pattern of liquid bath method

Table 3 Thermal shock conditions (liquid)

Step	Test condition	Number of cycles	Test condition	Number of cycles	Test condition	Number of cycles	Test condition	Number of cycles
	AA	5	**BB**	5	**CC**	5	**DD**	5
	AA-1	15	**BB-1**	15	**CC-1**	15	**DD-1**	15
	AA-2	25	**BB-2**	25	**CC-2**	25	**DD-2**	25
	Temperature (˚C)	**Time**	**Temperature (˚C)**	**Time**	**Temperature (˚C)**	**Time**	**Temperature (˚C)**	**Time**
1	-0^{+2}_{-10}	See table 5	-65^{+0}_{-10}	See table 5	-65^{+0}_{-10}	See table 5	-65^{+0}_{-10}	See table 5
2	100^{+10}_{-2}	See table 5	125^{+10}_{-0}	See table 5	150^{+10}_{-0}	See table 5	200^{+10}_{-0}	See table 5

Table 4 Recommended fluid

Test Conditions	Condition A	Condition B	Conditon C	Condition D
Step 1	FC-40 (or water) D02 D02-TS D/80	FC-77 D02 D02-TS D/80	FC-77 D02 D02-TS D/80	FC-77 D02 D02-TS D/80
Step 2	FC-40 (or water) D02 D02-TS D03	FC-70 D02-TS FC-40 D03 UCON-WS D02	FC-70 D02-TS FC-40 D03 UCON-WS D02	FC-70 LS/230 FC-40 LS/215 UCON-WS D02

Note:
• Ethylene glycol shall not be used.
• When using water as low temperature fluid, a mixture of water and alcohol may be used to prevent freezing.

Table 5 Exposure time in liquid at temperature extremes

Weight of specimen	Minimum time (for steps 1 and 2): Minutes
0.05 ounce (1.4 grams) and below	1/2
Above 0.05 ounce (1.4 grams) to 0.5 ounce (14 grams)	2
Above 0.5 ounce (14 grams) to 5 ounces (140 grams)	5

The special features of this standard are as follows.
a) Exposure time has been clearly determined according to specimen weight.
b) Specimens can be transferred within 10 seconds.
c) Testing may not be interrupted during the prescribed cycles.

1-4-3 MIL-STD-883D Test Methods and Procedures for Microelectronics

(1) Test Method: 1010.7
Temperature Cycling (air chamber method)

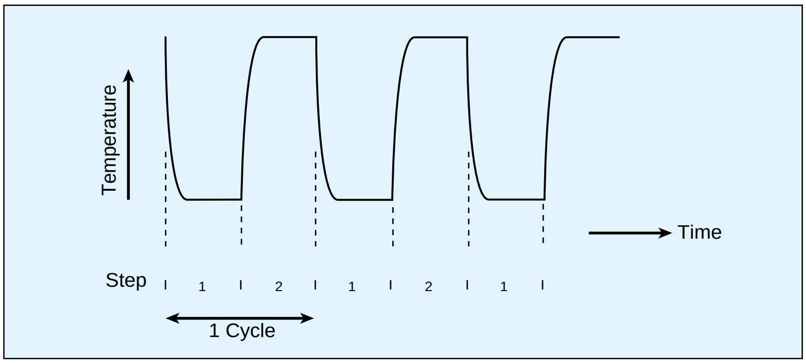

Fig. 7 Test pattern of temperature cycling (air chamber method)

Table 6 Temperature-cycling test conditions

Step	Minutes	Test condition temperature (˚C)					
		A	B	C	D	E	F
1 Cold	≧10	-55^{+0}_{-10}	-55^{+0}_{-10}	-65^{+0}_{-10}	-65^{+0}_{-10}	-65^{+0}_{-10}	-65^{+0}_{-10}
2 Hot	≧10	85^{+10}_{-0}	125^{+15}_{-0}	150^{+15}_{-0}	200^{+15}_{-0}	300^{+15}_{-0}	175^{+15}_{-0}

Note:
Steps 1 and 2 may be interchanged. The load temperature may exceed the + or – zero (0) tolerance during the recovery time. Other tolerances shall not be exceeded.

The special features of this standard are as follows.
a) The two zone method is used.
b) Minimum exposure time after transferring specimens is 10 minutes.
c) Worst case specimen recovery time is 15 minutes maximum.
d) Specimens can be transferred within 1 minute.

(2) Test Method: 1011.9
Thermal Shock (liquid bath method)

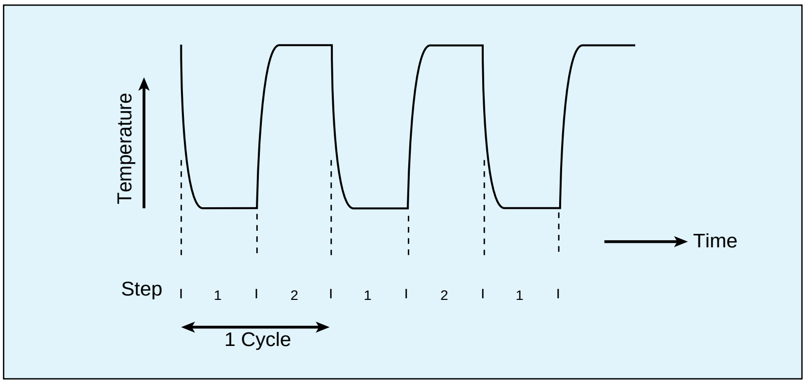

Fig. 8 Test pattern of thermal shock (liquid bath method)

Table 7 Thermal shock temperature tolerances and suggested fluids

Test conditions		A	B	C
		Temperature	Temperature	Temperature
Step 1	Temperature tolerance (˚C)	100^{+10}_{-2}	125^{+10}_{-0}	150^{+10}_{-0}
	Recommended fluid	Water	Perfluorocarbon	Perfluorocarbon
Step 2	Temperature tolerance (˚C)	-0^{+2}_{-10}	-55^{+0}_{-10}	-65^{+0}_{-10}
	Recommended fluid	Water	Perfluorocarbon	Perfluorocarbon

Table 8 Physical property requirements of perfluorocarbon fluids

Test conditions		B	C	ASTM test method
Step 1	Boiling point (˚C)	>125	>150	D1120
	Density at 25˚C (gm/ml)	>1.6		D941
	Dielectric strength (volts/mil)	>300		D877
	Residue (microgram/gram)	<50		D2109
	Appearance	Clear, colorless liquid		Not applicable
Step 2	Density at 25˚C (gm/ml)	>1.6		D941
	Dielectric strength (volts/mil)	>300		D877
	Residue (microgram/gram)	<50		D2109
	Appearance	Clear, colorless liquid		Not applicable

Note:
The perfluorocarbon used shall have a viscosity less than or equal to the thermal shock equipment manufacturer's recommended viscosity at the minimum temperature.

The special features of this standard are as follows.

a) Minimum exposure time is 2 minutes.
b) Specimen temperature reaches prescribed temperature within 5 minutes.
c) Specimens can be transferred within 10 seconds.
d) Testing may not be interrupted during the prescribed cycles.
e) The old test method 1011.7 recommended fluids for use, but the current standards make physical properties requirements for fluids.

* Sections 1-4-2 and 1-4-3 give only a summary of the standards for reference. For details, consult the original standards.

1-5 Precautions for Thermal Shock Testing

Example 1

Fig. 9 shows changes in conductor resistance when the PWB has undergone Thermal Shock Testing. The graph indicates that the greater the difference in temperature conditions, the quicker changes appear in characteristic values.

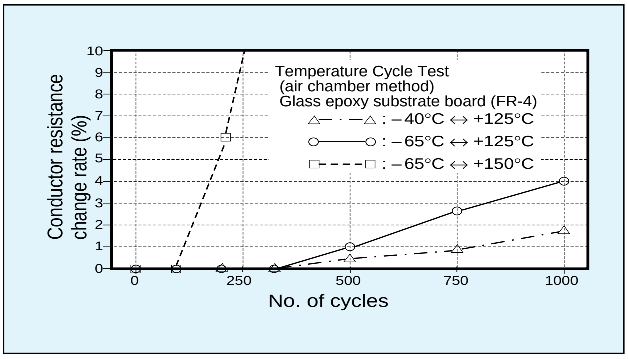

Fig. 9 Changes in conductor resistance under different temperature conditions

<Presentation: Chubu Electronics Development Association, “Study on Reliability of Printed Circuit Boards (sixth), — on Efficient Conditions of Thermal Shock Test—”>

Example 2

Fig. 10 and 11 show the results of Thermal Shock Testing using the same temperature gap at different temperature settings for a 7 segment LED.

In this case, the maximum temperature can be assumed to accelerate failure more than the temperature gap.

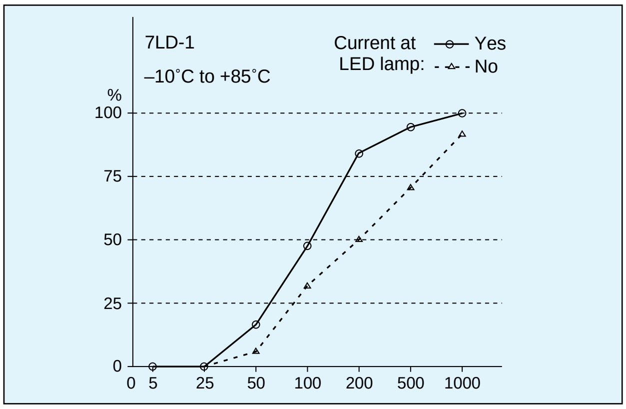

Fig. 10 –10°C to +85°C

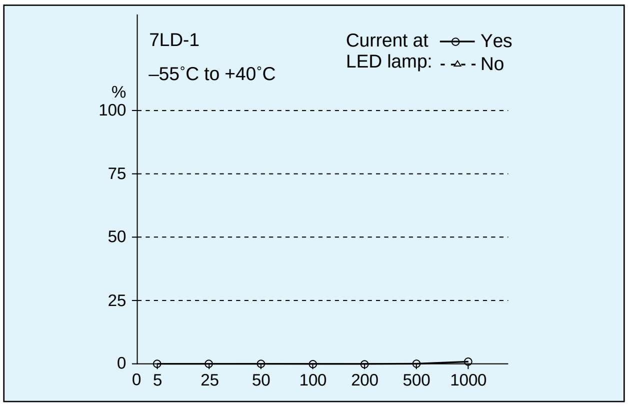

Fig. 11 –55°C to +40°C

Example 3

Fig. 12 shows the results of different test conditions for resin mold IC in performing Thermal Shock Testing. Under test conditions 1 the line turned up at approximately 1,700 cycles, and under test conditions 4 the line turned up at approximately 900 cycles, leading us to hypothesize a change in the failure mode.

<Presentation: Union of Japanese Scientists and Engineers publication, “Reliability Testing: Outline and Equipment Parts”>

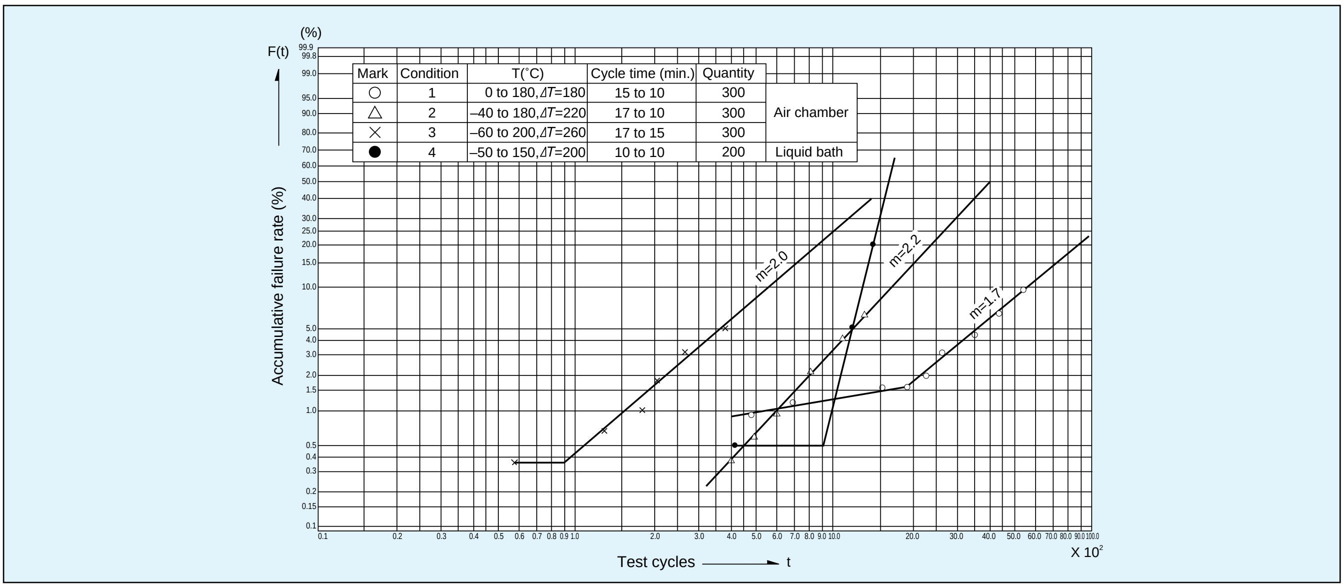

Fig. 12 Results of resin mold IC Thermal Shock Testing

From these results, we can see that test outcomes vary widely depending on:

- Temperature differences in test conditions,
- Highest temperature, and
- Number of cycles

In addition, other conditions that exert major influence on test results include both “exposure time” and “temperature recovery time (temperature change rate)”.

To calculate “exposure time”, the internal parts of the specimen must also have reached the prescribed temperature. If exposure time is too short, only the surface of the specimen will receive thermal shock. Furthermore, if “temperature recovery time” is too long (that is, “temperature change rate” is small), differences in the coefficients of thermal expansion will not show up clearly, and expected test results will not be obtained. Also, when a large specimen is used, or when numerous specimens are tested at one time, the temperature recovery time will vary greatly depending on the position, so care must be taken with temperature measurement position and temperature control position.

Thermal Shock Testing is a severe test method even among the different types of environmental testing, and setting test conditions can be difficult. The correlation between test conditions and failures that occur in the field must be considered carefully to properly determine test conditions.

1-6 Equipment for Thermal Shock Testing

When selecting equipment for Thermal Shock Testing, one must of course consider reliability, maintainability, and ease of operation, but in addition, care must be taken with the following items.

For the air chamber method:

1) Can appropriate temperature recovery time be obtained for specimen volume?
   1. Of course temperature recovery performance is affected by the position of the specimen.
      However, a large difference in recovery performance is problematic, so as far possible equipment with good temperature uniformity must be selected.
   2. Is the temperature control sensor positioned properly for test conditions?
      A temperature control sensor and temperature measurement sensor that can alternate either upstream or downstream of the specimen is preferable.
   3. Are auxiliary cooling methods such as liquefied carbon dioxide and liquefied nitrogen being used?
2) MIL-STD-202F Testing method 107G is a three-zone testing method that includes normal temperature exposure (Step 2, step 4).
   MIL-STD-883D Testing method 1010.7 is a two-zone testing method that doesn't include normal temperature exposure.
   Equipment can be either of the two-zone type or a type that can alternate between two-zone and three-zone testing. Equipment selection must be carefully based on testing conditions.

For the liquid bath method:

1) Can appropriate temperature recovery time be obtained for specimen volume?
   Note: Since fluid with a high thermal capacity is usually stirred inside the chamber in the liquid bath method, major differences do not occur in temperature recovery time depending on the positioning of the specimen such as occur in the air chamber method.
2) Is the amount of fluid consumed small?

We would like to introduce the following products of our company, including those produced by our American subsidiary, ESPEC CORP.

AIR-TO-AIR
THERMAL SHOCK CHAMBERS TSA SERIES

ESPEC's CFC free TSA Thermal Shock Chambers are newly designed with upgraded features and performance. True horizontal air-flow improves temperature and product gradient. The conditioned air is changed via a Damper System, which does not require the product to be moved. This design makes thermocoupling the product to movement which could produce vibration and shock.

An automatic vertical sliding door makes loading and unloading extremely easy and saves valuable floor space.

Model	Temperature range	Test area Volume cu. ft.	Test area dimensions W × D × H mm (in)
TSA-70H	High temp. chamber: +60 to +200°C (+140 to +392°F) Low temp. chamber: –70 to 0°C (–94 to +32°F)	2.5	410 × 370 × 460 (16.1 × 14.6 × 18.1)
TSA-70S			410 × 370 × 460 (16.1 × 14.6 × 18.1)
TSA-100S		3.9	650 × 370 × 460 (25.6 × 14.6 × 18.1)
TSA-200S		7.1	650 × 670 × 460 (25.6 × 26.4 × 18.1)
TSA-40L	High temp. chamber: +60 to +200°C (+140 to +392°F) Low temp. chamber: –65 to 0°C (–85 to +32°F)	1.4	240 × 370 × 460 (9.4 × 14.6 × 18.1)
TSA-70L		2.5	410 × 370 × 460 (16.1 × 14.6 × 18.1)
TSA-300L		10.6	970 × 670 × 460 (38.2 × 26.4 × 18.1)

LIQUID-TO-LIQUID
THERMAL SHOCK CHAMBERS TSB-2 TSB-5

ESPEC has seen a great increase in demand for high-performance, high-intensity thermal shock chambers in many fields, especially in the electronics industry. Our liquid to liquid chambers are excellent for imposing high thermal stress on specimens. Operating costs are reduced as a result of lower fluid consumption achieved by the air-tight test chamber and an automatic rotary shutter at the bath inlet. Two types of fluid can be used by simply changing a valve. The dedicated Al controller can automatically determine appropriate pre-heating and pre-cooling as well as test conditions. These chambers also exhibit exceptionally short temperature change periods.

Model	Temperature range	Test area Volume cu. ft.	Test area dimensions W × D × H mm (in)
TSB-2	High temp. chamber: +70 to +200°C (+158 to +392°F) Low temp. chamber: –65 to 0°C (–85 to +32°F)	0.08	120 × 120 × 150 (4.7 × 4.7 × 5.9)
TSB-5		0.16	150 × 200 × 150 (5.9 × 7.8 × 5.9)

AIR-TO-AIR THERMAL SHOCK CHAMBERS ETS SERIES

These thermal shock chambers incorporate an innovative Al controller for precise test environment control and ease of operation. A large graphic LCD enables even the inexperienced operator to quickly set the test conditions simply by following the directions displayed. The controller also provides on-line help recommending corrective action during alarm conditions.

A wide range of performance is available, with a 22 lb (10 kg) load, of molded plastic ICs for example, the chambers demonstrate superlative temperature recovery characteristics recovering from +150°C/–65°C within 5 minutes using no auxiliary cooling. Multiple safety features guarantee the integrity of both specimen and chamber, and the advanced design achieves excellent maintainability by stressing ease of access for service.

Model	Temperature range	Test area Volume cu. ft.	Interior dimensions W × D × H mm (in)
ETS4-1SW	Hot box: Ambient to +210°C (Ambient to +410°F) Cold box: –75 to +40°C (–103 to +104°F)	4	500 × 500 × 400 (20 × 20 × 16)
ETS4-2SW			
ETS4-3SW			
ETS13-3SW		13	660 × 830 × 630 (26 × 33 × 25)
ETS13-5SW			

PWB CONDUCTOR RESISTANCE EVALUATION SYSTEM

Cracking in PWB through holes and solder junctions leads to broken wires and contact defects, which significantly degrade electronic product reliability. Both internal and external factors cause cracking. Internal factors include the method of contact, the solder quality, the type of flux activator, and the cleaning method. External factors include such environmental stress as temperature and humidity. The PWB Conductor Resistance Evaluation System detects cracking from changes in conductor resistance, through connecting the Thermal Shock Chamber with the Measurement System. This system can also be used for testing such contact equipment as connectors and switch relays.

(The photo shows a system example of the model with the Thermal Shock Chamber.)

Resistance measurement range	10^{-3} to 10^{4} Ω
Measurement time	approximately 4 seconds
Measurement range	10mΩ, 100mΩ, 1Ω, 10Ω, 100Ω, 1kΩ, 10kΩ
Measurement power	AC 1µA, 10µA, 100µA, 1mA, 10mA (rms)
Measurement frequency	1 kHz
Maximum applied voltage during measurement	20 mV
No. of measurement channels	40 points (maximum 280 points)

2. *Combined Environmental Testing: Current Trends and Examples*

2-1 Summary of Testing

Current products are being produced with an ever-increasing number of parts that are both miniaturized and require higher precision. As each product bears higher level functions, not only must parts be tested, but the final products must also undergo testing.

Testing serves to evaluate and guarantee product safety, durability, and reliability for the environments in which the products are used. By setting test conditions that are more severe than products encounter in actual use, testing can find product limits and defects, and can be used to select measures for improving product design.

Combined Environmental Testing uses multiple environmental factors for testing together, such as temperature and humidity cycles or low temperature and low pressure. However, in this report we would like to discuss ranges of testing under the combined conditions of temperature environment with vibration environment, and (temperature) humidity environment with vibration environment.

2-2 Environmental Conditions for Combined Environmental Testing

Combined Environmental Testing conditions include both the primary environment, which is a natural environment, and the secondary environment, which is an induced environment.

The natural environment, as implied by the expression, is one created by nature, and is determined by the season, altitude, and the specific site on the planet. Atmospheric environment factors predominate.

The induced environment is an artificial one in which the main environment is created by the base on which the part or product is shipped or used, and also by the surroundings (called the platform). Mechanical environment factors predominate. Fig. 13 shows the general factors (not limited to temperature, humidity, and vibration) for each environment.

In addition, when considering the shipping and usage environments as platforms, the relationship between the phenomena and environmental vibrations that occur in those platforms are shown in Fig. 14.

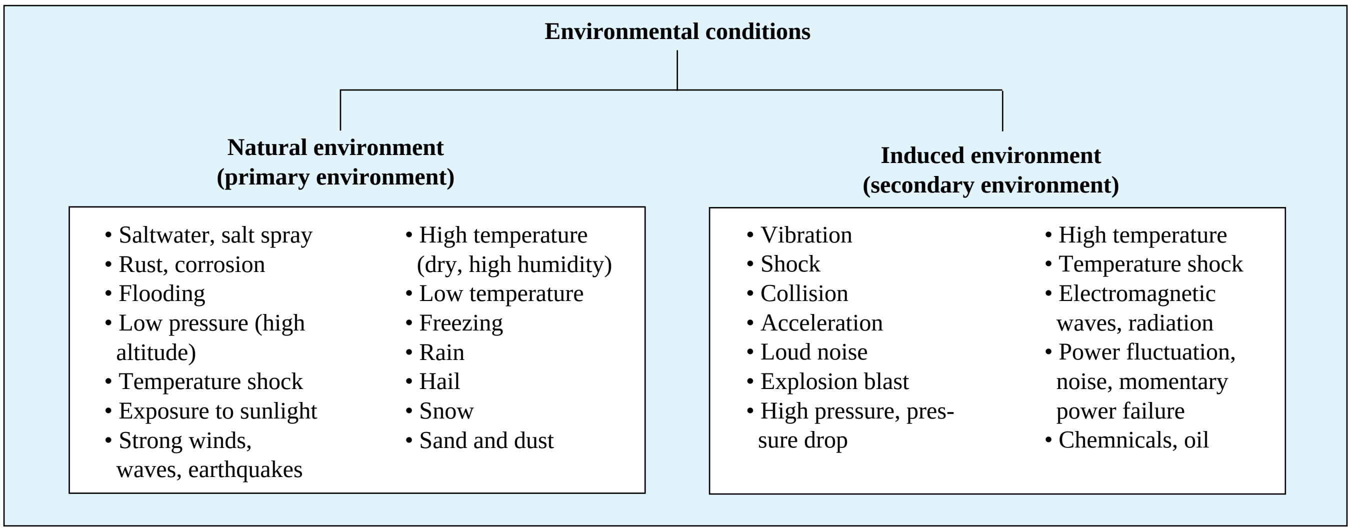

Fig. 13 Factors of environmental conditions in Combined Environmental Testing

Shipping environment

Platform type	Relationship between the phenomena and environmental vibration		
Truck shipping	Road vibration	RANDOM*1	Vibration from the roughness of the road surface is transmitted to the freight bed of the truck through the tires and suspension. Since the road surface is irregular, this vibration is random.
	Road shock	SHOCK	The freight bed can receive shock from differences in road surface levels due to construction or to potholes in the road.
	Freight handling shock	SHOCK	Shock from rolling, falling, dropping, or collision
Railroad shipping	Railroad vibration	RANDOM	Vibration is caused by the irregularity of the rails, and is transmitted through the suspension. This vibration is random.
	Shunting shock	SHOCK	Shock from collisions between the freight cars when starting, stopping or connecting the freight cars.
	Freight handling shock	SHOCK	Shock from rolling, falling, dropping, or collision
Freighter shipping	Wave vibration	SINE	Long waves that are equal to or longer than the length of the ship moves the entire ship in the form of a sine wave. If the characteristic (natural) frequency of the ship coincides with the wave, the ship can break at resonance peak. This long period sine wave vibration does not directly affect the freight.
	Wave shock	SHOCK	Shock from breaking waves that hit the ship
	Engine vibration	SINE ON RANDOM*2 RANDOM ON RANDOM*3	Vibrations from diesel engines and turbine engines are transmitted to the freight as sine on random or random on random vibrations.
	Freight handling shock	SHOCK	
Air freight shipping	Aerodynamic vibrations	RANDOM	Vibrations caused by turbulence on the main wings and body are random vibrations.
	Engine vibration: Jet	RANDOM	
	Engine vibration: Propeller	RANDOM ON RANDOM	
	Engine vibration: Helicopter	SINE ON RANDOM	
	Landing shock	SHOCK	
	Freight handling shock	SHOCK	

Usage Environment

Platform type	Relationship between the phenomena and environmental vibration		
Portable products	Freight handling shock	SHOCK	
	Handling shock	SHOCK	
	Environment identical to shipping environment		Without packaging materials
Marine equipment	Wave vibration	SINE	Ship construction
	Wave vibration	SHOCK	
	Engine vibration	SINE ON RANDOM RANDOM ON RANDOM	
Aircraft equipment	Aerodynamic vibration	RANDOM	
	Noise vibration	RANDOM	
	Engine vibration: Jet	RANDOM	
	Engine vibration: Propeller	RANDOM ON RANDOM	
	Engine vibration: Helicopter	SINE ON RANDOM	
	Landing shock	SHOCK	
	Running vibration	RANDOM	
	Emission vibration	SHOCK ON RANDOM	
Automobile equipment	Road vibration	RANDOM	Mainly equipment mounted on body
	Engine vibration: Engine, Transmission, Equipment mounted on the intake/exhaust system	SINE ON RANDOM	
	Engine vibration: Inside the engine compartment	RANDOM ON RANDOM	
	Road shock	SHOCK	
	Collision	SHOCK	Seats, vehicle body, air bag system, seat-belt system
Stationary equipment	Vibration from revolving equipment	SINE ON RANDOM	
Stationary equipment	Handling shock	SHOCK	
	Handling collision	SHOCK	

*1 RANDOM .... Random vibration lacks periodicity, and it is impossible to put it into a formula on the time axis, so the probability density function of the vibration amplitude can be expressed as a near normal distribution power spectrum.
*2 SINE ON RANDOM .... In broadband pulse, multiple sine wave pulse occur simultaneously with the revolving pulse of the main driving power.
*3 RANDOM ON RANDOM .... In broadband pulse, multiple random pulse occur simultaneously with the revolving pulse of the main driving power.

Fig. 14 Relationship between environmental vibration and phenomena occurring during shipping and usage

2-3 Examples of Combined Environmental Testing

When performing an actual test, generally one must determine both test time and test method.

To perform a test effectively, severe stress is applied to accelerate the chemical and physical causes of degradation of the parts and products. This acceleration reduces evaluation time and makes it possible to estimate the life and failure rate of the parts and products under the conditions in which they are used. When the products are actually shipped and failure occurs during shipping or during use, the causes of failure are not sought through normal standards testing. Tests that can recreate actual environmental conditions must be used to find the causes by forcing the failure to recur. On this occasion, Combined Environmental Testing must be carried out in a way that can be estimated to more faithfully reproduce the actual environment.

And now we would like to present examples of Combined Environmental Testing recreating the shipping environment and usage environment.

2-3-1 Examples of Combined Environmental Testing for Transportation Environment

At present, the field considered to be performing the most extensive Combined Environmental Testing in Japan is the automotive field.

Non-standardized tests on automotive parts are generally performed using test conditions designed according to decisions made by automotive manufacturers or parts manufacturers. For example, in SAE (Society of Automotive Engineers) standards the lower limit for temperature is –40°C, and the vibration testing range is from 1 to 1000 Hz, and these are used as reference values for performing combined testing of temperature and vibration.

Conditions may be determined by shipping routes, as, for example, a variety of shipping routes are used for consumer durables. A diversity of shipping methods are also used, such as freighters, aircraft, railroads, and automobiles. Depending on the shipping method and the weather of each area, a variety of environments can be encountered during shipping.

For example, since the Gulf War, shipping from Japan to Europe via the Suez Canal has been changed to the Trans-Siberian Railroad, causing major changes in shipping environment variables such as temperature, humidity, and vibration. An explication of the product complaints arising from this shipping route are an excellent example of the power of Combined Environmental Testing.

To test packaging for shipping via the Trans-Siberian Railroad, we used long-term shelf storage at –40°C, and then we added power spectrum random vibration testing determined by the shipping conditions. We used this kind of Combined Environmental Testing to obtain our results.

Next, we would like to present some examples of that testing.

Combined Environmental Testing of equipment shipped by rail (example)

Packages with heat sinks installed on electronic parts were arriving in Europe with defects (the legs were broken off) caused by the heat sink weight, and so various kinds of tests were performed. Testing confirmed that vibrations at low temperature could reproduce the defect.

Summary of Test Methods

1) Parts and equipment subject to testing were any specimens shipped on the Trans-Siberian Railroad.
   In addition, items planned for future shipping were included for testing.
2) Conditions and Testing
   1. Parts and equipment were testing in their final shipping packaging. (specimens included both those packaged individually and those in cartons.)
   2. Number of specimens were one or more at random.
   3. Specimens were placed on the shipping platform without being fastened in place, and vibration testing was performed using the following conditions. The direction of vibration amplitude was limited to vertical only, but when the number of samples was n = 3 or more, vibration amplitude was permitted in 3 directions.
      - Vibration/Driving time
        Vibration frequency ....5 to 50 Hz
        Power spectral density ....0.015 G^2/Hz
        Overall r.m.s. value ....0.83 G
        (random wave vibration)
        Vibration time ....46 minutes
      - After maintaining –40°C for at least 5 hours, vibration was applied in the –40°C environment.

      Cooling and temperature recovery time periods had to be at least 2 hours to avoid abrupt temperature changes.
   4. After low temperature vibration testing is finished, temperature recovers to normal temperature, and specimens are left at normal temperature for a minimum of 3 hours. Finally, parts are checked for abnormalities, including changes in appearance, general operation, and an internal parts inspection.

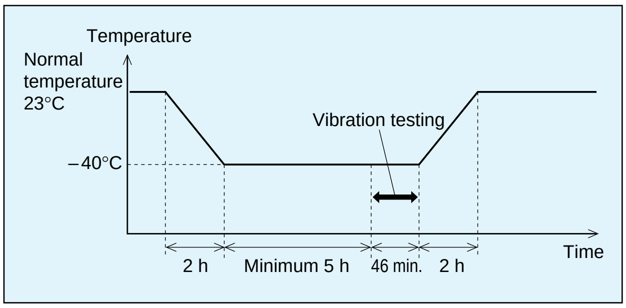

Fig. 15 Example of Combined Environmental Testing of equipment shipped by rail

2-3-2 Example of Combined Environmental Testing for Usage Environment (Vehicular Equipment)

An increasingly large number of car electronics parts are used in modern vehicles.

The ECU (Electronic Control Unit, with a built-in microcomputer) in modern automobiles performs reliability evaluation testing including Combined Environmental Testing set by the internal standards of each manufacturer.

Since the operating environment of the ECU is the vehicle, conditions for failure analysis need to be as close to actual vehicular running conditions as possible, proliferating manufacturers who produce Combined Environmental Testing equipment. Introductory studies have begun on the "multiaxial simultaneous vibration + random vibration + combined temperature and humidity chamber" as a unit that can perform Combined Environmental Testing at conditions resembling those in the actual environment.

Next, we would like to present some examples of that testing.

Example 1 Combined Environmental Testing of vehicle audio equipment

When an automotive heater is turned on after a car has been parked in a cold area, such as at a ski resort, the vehicle audio system bears the stress of an abrupt change in temperature. One manufacturer has performed Combined Environmental Testing that considers vibration after the car has been started in these conditions.

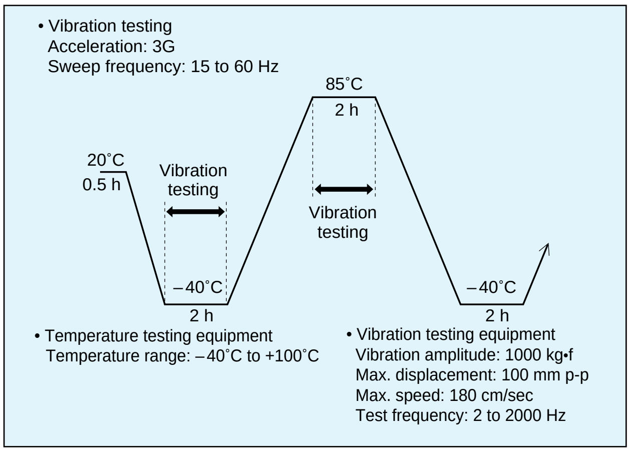

Fig. 16 Example of Combined Environmental Testing of vehicle audio equipment

Example 2 Combined Environmental Testing of assembly unit with air bag sensor

Because of the emphasis on improving safety in recent years, air bag systems have become common to protect passengers in vehicle collisions. Combined Environmental Testing is performed to confirm the reliability of the assembly unit with sensor used in these air bag systems.

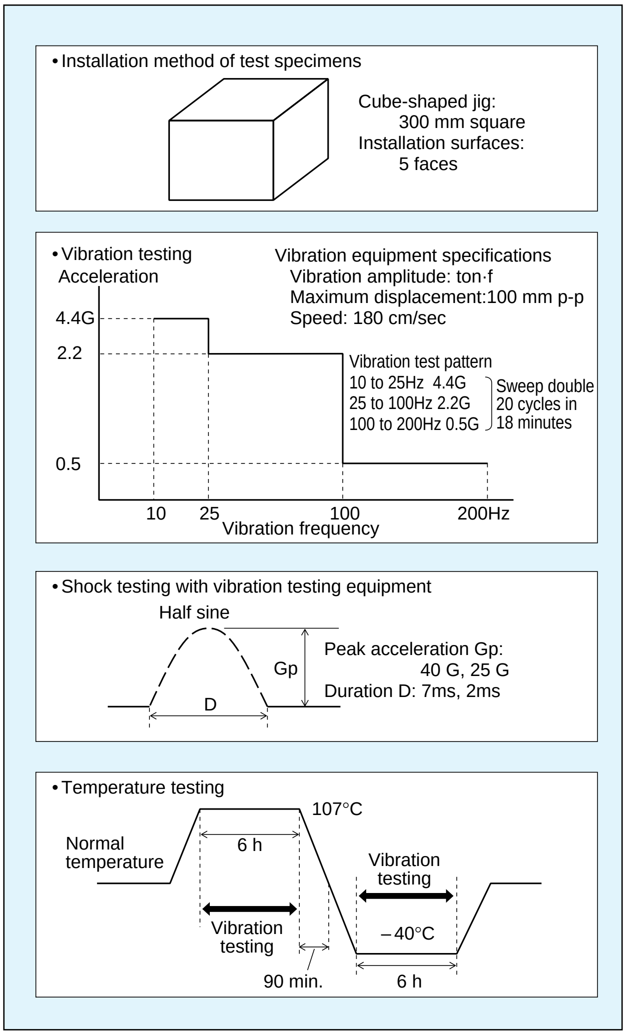

Fig. 17 Example of Combined Environmental Testing of assembly unit with air bag sensor

2-4 New Combined Environmental Testing Methods

With recent advances in controllers for vibration testing, tests can not only do sine wave vibration testing, but can also do random wave and shock wave testing. By connecting several vibration generators to the vibration platform, a system has been developed that can be switched among multiple axes (X, Y, and Z). Another system has been developed that can simultaneously vibrate all three axes, and should become widely employed in the 90's. Shipping environment reliability can be evaluated more effectively using testing that resembles actual vibration experienced during shipping. This kind of testing can be performed with a Combined Environmental Test System using temperature (humidity) environment with multiaxial vibration. At present, however, testing methods for closely duplicating actual environments are just beginning to be widely adopted.

2-4-1 (Mechanical) Shock Testing

Standards for shock testing methods, such as test method 213 of MIL-STD-202F (Test Methods for electronic and electrical component parts), and JIS-C-0041 (1995), 0042 (1995), clarify testing aspects such as purpose, methods, and range of application.

Conventional Shock Testing uses machines to generate shock with such methods as free fall and elastic rebound. For special purpose products (e.g., missile bodies and missile guidance equipment), one method is to perform MIL standards half sine shock testing using a large Water-cooled Vibrating Test System (vibration amplitude force 8 to 30 ton·f).

As ever more powerful shock testing methods are being developed, Shock Testing is being adopted for many parts and products. Powerful Shock Testing has become possible through the development of maximum 3000 kg·f air cooled electrodynamic vibrators with long stroke (40 to 100 mm P-P, low cost multifunctional controllers (sine, shock, random) and switching methods utilizing high power amplifiers. This type of equipment has made possible top speeds of up to 200 cm/sec.

Types of shock parts and products receive

Portable equipment such as video cameras and mobile audio devices
..... Shock received while being carried
Automotive CD, display meters, displays, ECU
..... Shock received while driving
Automotive harnesses, connectors, tail lamps
..... Shock received when opening or closing doors and trunk
Computer CD-ROMs and hard disk drives
..... Shock received during operation

Combined Environmental Testing using sine and random vibration together has been used on these parts and products, but more recently Shock Testing has also become possible by combining low cost digital controllers with electrodynamic vibration testers. Concurrently, requirements for Combined Shock Testing have also been increasing. Special characteristics of integrated dampers, which aim to reduce shock and vibration from external sources, are affected by temperature, and parts and products need to have vibration resistance evaluated using Combined Environmental Testing.

Vibration testing performed as one aspect of Combined Environmental Testing can consist of components from sine wave testing to random wave testing and shock testing. This provides combined testing that more closely resembles the actual environment, creating evaluation testing conditions closer to ideal conditions, and making endurance testing possible.

Photo. 9 shows an example of delivery of a Combined Environmental Test System. Here, the TABAI ESPEC Temperature/Humidity Chamber is connected to the Vibration Generator using the chamber bottom direction connection method.

Compared with the connecting shaft method, this chamber bottom direction connection method:

- Has no acceleration loss due to the added weight of the connecting shaft.
- Has a ceiling frequency that fulfills performance specifications of the vibrating system.
- Has the advantage of being easier to operate with lower specimen installation section where the connecting shaft is not needed.

Photo. 9 Vibration generator connected to temperature/humidity chamber

2-4-2 Combined Multiaxial Testing

The vibration parts and products receive during shipping is not limited to simple one direction vibration. Vibration can occur simultaneously in two or three directions (X, Y, and Z axes).

Vibration-induced loss has become of greater concern due to the increasingly high performance levels of parts and products now in use for aircraft and automobiles, electric and electronic parts, and items with structural and architectural applications. Such high performance levels mean that reliability must be pursued through testing conditions that are much more severe than public standards. Vibration test environments must more closely reflect actual environmental conditions, and so multiaxial, multidimensional vibration testing equipment is becoming more and more widely used.

One example of this is the cobblestone roads in Europe that cause a severe up/down vibration creating abnormalities in the sound field environment of the vehicle interior. One manufacturer performed testing that recreated the vibration of the actual driving environment, resulting in their being able to improve quality.

Low frequency range vibration testers were developed early for shipping package testing used on large heavy items.

Also, conventional single axis vibration generators had to be changed over from horizontal to vertical during testing, making it necessary to perform the following complex operation.

1) Remove specimens.
2) Dismantle horizontal vibration platform.
3) Rotate vibration generator 90 degrees.
4) Couple vertical vibration platform.
5) Install specimens.

And further, since the vertical and horizontal vibration platforms are not the same height, in some cases preparations had to be made for connecting each with the temperature/humidity chamber.

MIL, JIS, and IEC standards testing is now possible using high frequency, high acceleration generation at the same level as with single axis vibration equipment.

Specimens tested together on the same table can be vibrated vertically and horizontally without re-setup of the stage or changeover, and can be switched from single direction vibration to two or three directions by connecting one temperature/humidity chamber. This ease of operation makes combined multiaxial testing possible using simultaneous multidimensional vibration.

On Multiaxial Vibration Test Systems, simply flipping a switch enables changing between vertical and horizontal vibration. Testing has also become possible on two and three axes simultaneously. Setting the time sequence enables endurance testing interconnecting the vertical and horizontal axes while linked to the temperature and humidity chamber. This testing can be performed with the same installation, without stopping the chamber, without setting up the stage again, and without changing the specimens.

Fig. 18 shows an example of multiaxial stress, and Photo. 10 shows an equipment sample.

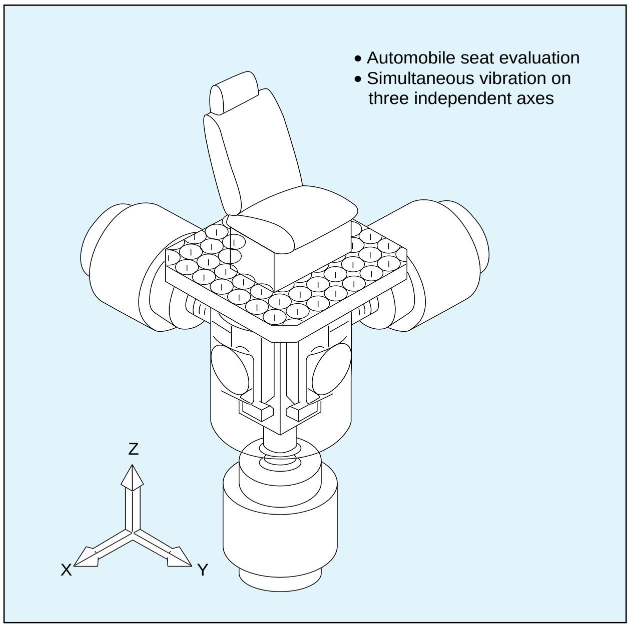

Fig. 18 Multiaxial stress

Photo. 10 Multiaxial Combined Environmental Test System

2-5 Summary

The driving force behind current industrial product development includes high level functions, higher reliability, lower electrical consumption, and lower cost. These benefits have been made possible by the development of LSI technology, surface mounting technology, and liquid crystal displays. Sensor actuators and ECUs have provided great strides in car electronics technology, and vehicle equipment has become increasingly miniaturized and the number of products has increased. Mobile unit communications and portable AV equipment is becoming ever more rapidly adopted.

This type of market development creates the following demands.

1) Demand is growing for safety and reliability to be more widely guaranteed for high-tech specialist equipment that is increasingly being marketed for the general consumer.
2) The accelerating pace of technical innovation reduces development time for new products, making faster reliability evaluation ever more crucial.
3) To reduce the incidence of early failure, it is becoming more and more critical to eliminate defects in the production process and to actualize latent defects of devices.
4) Strong demand exists for ways to improve the ability to analyze failure due to combined environmental factors.

Reliability testing must become more accurate and evaluation must become faster to improve the ability to efficiently analyze market complaints. The role played in this process by Combined Environmental Testing is becoming more important, and we expect even greater developments in this field of technology in days to come.

2-6 Equipment for Combined Environmental Testing

TEMPERATURE (HUMIDITY) AND VIBRATION COMBINED ENVIRONMENTAL TESTING CHAMBER

This environmental testing chamber creates combined environmental stress by combining atmospheric environmental stress such as temperature and humidity with physical (mechanical) environmental stress such as shock, vibration, and acceleration.

Model	Temperature and humidity range	Internal dimensions W × H × D mm (in)
PVL-2SP	–40 to +100˚C (–40 to + 212˚F) 20 to 98%RH	500 × 750 × 600 (19.7 × 29.5 × 23.6)
PVL-3SP		600 × 850 × 800 (23.6 × 33.5 × 31.5)
PVL-4SP		1000 × 1000 × 800 (39.4 × 39.4 × 31.5)
PVS-2SP	–70 to +100˚C (– 94 to +212˚F) 20 to 98%RH	600 × 850 × 600 (23.6 × 33.5 × 23.6)
PVS-4SP		1000 × 1000 × 800 (39.4 × 39.4 × 31.5)
PVU-2SP	– 40 to +100˚C (–40 to +212˚F)	500 × 750 × 600 (19.7 × 29.5 × 23.6)
PVU-3SP		600 × 850 × 800 (23.6 × 33.5 × 31.5)
PVU-4SP		1000 × 1000 × 800 (39.4 × 39.4 × 31.5)
PVG-2SP	–70 to +100˚C (–94 to 212˚F)	600 × 850 × 600 (23.6 × 33.5 × 23.6)
PVG-4SP		1000 × 1000 × 800 (39.4 × 39.4 × 31.5)

Model	Applied vibration force	Maximum load*	Model	Applied vibration force	Maximum load*
V1	120kgf	66kg	**S1S**	100kgf	66kg
V2	200kgf		**S2S**	200kgf	116kg
V3	300kgf	116kg	**S3S**	300kgf	
V4		122kg	**S4S**		292kg
V5S	600kgf	192kg	**S5S**	500kgf	196kg
V6S	1000kgf	242kg	**S6S**	1000kgf	192kg
V7S		120kg	**S7S**		292kg
V8S	1500kgf	290kg	**S8S**	1500kgf	
V9S	2000kgf		**S9S**	2000kgf	492kg
V10S	3000kgf	492kg	**S10S**	3000kgf	

*Vibration generator performance when performing Combined Environmental Testing

COMBINED ENVIRONMENTAL RELIABILITY TESTING CHAMBER CERT SERIES

This reliability testing chamber reproduces individual or combined environments to test temperature vs. pressure, vibration vs. pressure, or temperature vs. pressure vs. vibration. This chamber is used for such reliability testing as aircraft and spacecraft parts and materials.

Model	Temperature and pressure range	Internal dimensions W × H × D mm (in)
CERT-22	–70 to +100˚C (–94 to 212˚F)/ 101 to 19 kPa (760 to 140 Torr)	1500 × 1000 × 1500 (59 × 39.4 × 59)
CERT-33	–70 to +100˚C (–94 to 212˚F)/ 101 to 7 kPa (760 to 54 Torr)	1500 × 1500 × 1500 (59 × 59 × 59)

3. Postscript

We have presented a three part series on environmental testing technology, with “Temperature Testing” in Part 1, “Humidity Testing” in Part 2, and both “Thermal Shock Testing” and “Combined Environmental Testing” in Part 3. We sincerely hope that everyone involved in leading edge research and technology development will find knowledge of environmental testing to be useful.

From our next issue we will begin a series on environmental testing from the standpoint of reliability testing, and we believe you won't want to miss it.

We shall be very pleased if you continue to find our articles worthwhile.

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