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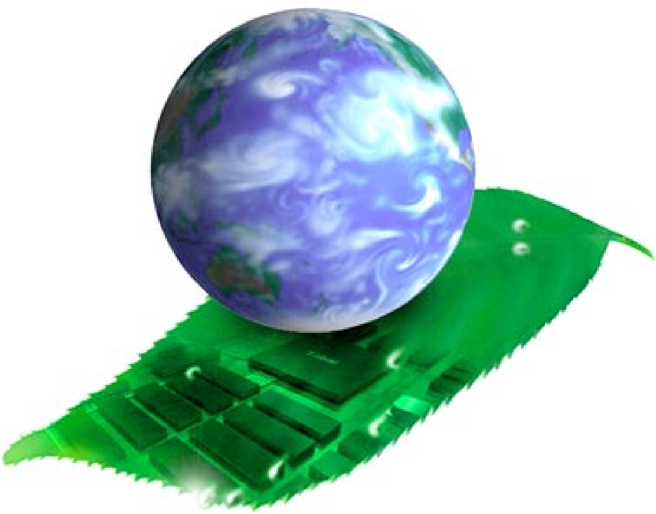
ESPEC

TECHNOLOGY REPORT

2000

No. 9

Special issue:
Evaluating Reliability and Non-destructive testing



CONTENTS

TABAI ESPEC CORP.

Our Philosophy

We at TABAI ESPEC are continually pursuing perfection. In our ongoing struggle to realize this ideal, we have established our Corporate Mind, which we proudly use as the basis for all our efforts. This Corporate Mind defines for us our present and future goals, directions and actions. At TABAI ESPEC, where “Environment” is our business, we offer aid for new technological developments and a more certain and improved living environment. With “Progress to Perfection” as our corporate policy, we aim to become the company, firstly “with public recognition by having our original line of business, and our own original product sphere by virtue of our original technology”, and secondly “with intellectual raison d’être of such that as specialists can, assist our clients and industry in setting up various issues and in finding answers to them”. This total concept we call ESPEC. From our internationally minded product development, to our thorough after-service, all our activities originate in this concept of ESPEC. ESPEC is the foundation upon which we manufacture products with superb performance, functional design and excellent cost-performance — our ESPEC.

ESPEC — our philosophy, our goal.

Corporate Data

TABAI ESPEC CORP.

Company Name:	TABAI ESPEC CORP.
Date founded:	July 25, 1947
Date incorporated:	January 13, 1954
Paid-up Capital:	6,778 million Yen (As of September, 1999)
Chairman:	Eiichi Koyama
President:	Kiyoshi Shimazaki
Senior Managing Director:	Yoshinobu Yamada
Managing Directors:	Susumu Nojii Toshikazu Adachi Nobuyoshi Shin
Directors:	Eishiro Hizukuri Yoshio Nakai Osamu Nakamatsu Hiromichi Fukumoto
Regular Auditor:	Katsuharu Nakano
Auditors:	Shoichiro Yoshioka Takuichi Omura Katsuyuki Kakihara
Employees:	600 (plus 57 temporary employees)

Product Guide

Environmental Test Chambers
- Temperature (& Humidity) Chamber
- Temperature (Humidity) & Vibration Combined Environmental Test Chamber
- Walk-in Type Temperature (& Humidity) Chamber
- HAST System (Highly Accelerated Stress Test System)
- Thermal Shock Chamber
- Temperature Chamber (Industrial Ovens)

Measurement Evaluation Systems
- Ion Migration Evaluation System
- PWB Conductor Resistance Evaluation System
- Environmental Test Chamber Network, E-Bus

Burn-in Test Systems
- Wafer Burn-in System
- Dynamic/Monitored Burn-in System

Automated Production Equipment
- Automatic Clean Cure System
- High Speed Clean Oven for Glass Sheet

Laboratory Chambers

Biomedical Chambers

Agribusiness
- Plant Factory
- Phyto-tron (Environmental Control Chamber for Plant)
- Growth Chamber

NOTE:
Some models are available only in the limited countries.

Non-destructive testing for product and facility safety

Kazuo Hirayama*

To insure product safety and reliability in the field of manufacturing, non-destructive testing is often used to eliminate potential defects before shipping and to analyze defects when accidents have occurred. Professor Hirayama of Osaka Sangyo University has contributed this article on the relationship between non-destructive testing and product safety and reliability.

1. Introduction

Approximately four years have passed since the Product Liability Law went into effect here in Japan in July 1995. Since that time, manufacturers have redoubled their efforts to supply safe products and facilities to comply with this law.

These days, the importance of non-destructive evaluation techniques has been greatly increasing in all fields of manufacturing. This technology is used to prevent accidents and breakdown, to analyze such accidents and breakdowns when they do occur, and to improve safety and reliability.

The purposes for using non-destructive methods can be grouped into two major categories. One area of non-destructive testing focuses on improving manufacturing processes by detecting defects that occur during those processes. The other major area consists of evaluating the quality and reliability life of products and facilities by achieving a quantitative understanding of the relationship between product defects and product strength.

In general, the term non-destructive testing (NDT) is used to refer to such techniques as examining types, shapes, and dimensions and determining whether a product has any internal or external defects. Such techniques do not cause damage to or destruction of the products.

The term non-destructive inspection (NDI) is also frequently used, but this term refers to techniques to determine product acceptance/rejection by comparing the non-destructive test results with pre-determined criteria. For the production line to run smoothly from the initial stages of production up to product completion, defects occurring at each process must be detected using non-destructive testing, those defects must be eliminated at early stages of the process, and defective products must not be introduced to the next process. Also, the cause of defect occurrence must be investigated and feedback from the investigation must be given to the production process. In this way, production line problems can be quickly detected, and countermeasures can be taken to prevent product defects.

In addition, preventive maintenance based on maintenance inspections is crucial to maintaining the safe operation of equipment and production items during their use. Maintenance inspections can be broadly classified into inspections with equipment running and inspections requiring equipment stoppage. Non-destructive testing according to the purpose is required to be able to diagnose deterioration due to materials as well as due to the occurrence of all sorts of defects caused by usage environment factors.

Nowadays, non-destructive methods are not only used to detect defects, but also to consider the effects of those defects on the reliability of equipment and production items. Research is also under way on general evaluation methods for reliability life and safety factors in fracture mechanics. These evaluation methods are called non-destructive evaluation (NDE).

Fig.1 below shows a sample flowchart of non-destructive evaluation with general considerations for welded structures.[1)]

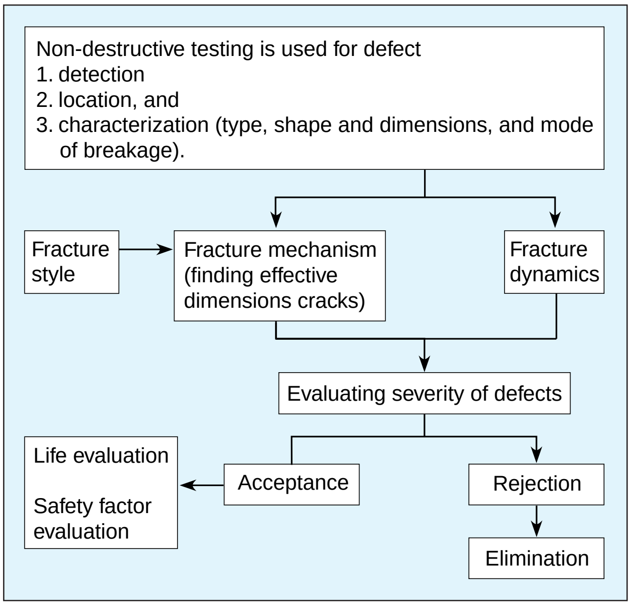


Fig. 1 Flowchart for non-destructive evaluation techniques

*Osaka Sangyo University

First of all, non-destructive testing is used to detect defects inside the materials, then defects must be located and differentiated according to type, and then characterized according to such factors as shape and dimensions.

Next, the load and environmental conditions are considered in hypothesizing the fracture mechanism, and defect severity is determined according to fracture dynamic handling. Using those results, the final acceptance/rejection determination (the last defect screening) is made, and accepted items are once more evaluated for safety factor and life.

2. *Types of non-destructive tests*

Most non-destructive testing methods are based on principles using properties such as ultrasonic frequencies, electromagnetism, and radioactive emissions, in other words utilizing physical phenomena. For reference, Table 1 shows NASA classifications of non-destructive measurement techniques.[2)]

The types of non-destructive tests can be grouped according to the locus of the test, for example, whether the test obtains information related to the internal section or whether it obtains information related to the surface or the surface layer. The following examples show non-destructive tests belonging to each of these categories.

(1) Non-destructive testing to obtain information related to the internal section

Radiographic testing and ultrasonic testing

(2) Non-destructive testing to obtain information related to the surface or the surface layer

Visual testing, liquid penetrant testing, magnaflux testing, and electromagnetic induction (eddy current) testing

At this point, I would like to discuss some representative non-destructive measurement techniques that have been gaining acceptance for application to product and facility safety.

3. *Radiographic testing*

Radiographic testing is widely used as a non-destructive test method for detecting defects inside test items. In particular, this type of test is used for checking welded joints in steel structures such as ships, tubing, bridge girders, and pressure vessels. Objective test results can be obtained regarding the type and dimensions of the defects detected, and so this test method is widely used for quality assurance of products and facilities.

Radiographic testing utilizes the properties of x-rays, γ-rays, and neutron rays to permeate matter. In other words, if there is an aperture inside the test item, the rays permeating that section will differ in intensity from the rays permeating the surrounding wholesome section. Detectors (e.g., x-ray film and instruments for measuring radiation) are used to create images showing the differences in intensity of such radiation, and observing these images can reveal the existence of apertures.

Radiographic testing can be broadly divided into direct methods, fluoroscopy methods, and digital methods.

3-1 Direct methods

Direct methods are the most common type of radiographic testing. In these techniques, the varying density of radiation that penetrates the test object is projected (irradiated) directly onto x-ray film, then the resulting photographic image is visually inspected.

Table 1 NASA standard classifications of non-destructive measurement techniques

Classification	Test methods	Classification	Test methods
Mechanical-optical methods	• Visual-optical method • Holographic interference method • Photoelastic membrane method • Stress paints • Strain gauge • Micro hardness • Liquid penetrant method • Volatile liquid method • Filter particle method • Leakage detection		• Electrical induction method • Natural electron emission method • Microwave emission
		Thermal methods	• Contact temperature measurement • Thermoelectromotive force method • Infrared radiometer method • Liquid crystal method • Electrothermal method
Radioactive transmission methods	• Radiographic test method • γ-ray radiography • Neutron radiography • Transmitted radiation measurement method • Back-scattering x-ray method • Auto-radiography • Radioactive gas penetrant method • Positron extinction method	Acoustic and ultrasonic methods	• Acoustic shock method • Acoustic vibration method • Eddy current noise vibration method • Acoustic emission method • Ultrasonic pulse reflection method • Ultrasonic permeation method • Ultrasonic surface wave method • Ultrasonic threshold angle method
Electromagnetic and electrical methods	• Magnetostatic field method • Magnetic particle method • Nuclear magnetic resonance method • Barkhausen effect • Eddy current method • Electrical resistance method • Charged particle method • Corona discharge method	Chemical and analytical methods	• Chemical spot test • Electrolytic probe method • Laser probe method • Ion scatter method • Ion probe method • Auger analysis method • Fluorescent x-ray method • Neutron emission spectroscopy • Charged particle emission method

The quality of direct radiographic images varies according to a number of factors such as the quality of the x-rays or γ-rays, focus dimensions, and the combination of photographic arrangement with the x-ray film used and the intensifying screen. In addition, to evaluate the image quality of radiographs, radiation meters consisting of wires of various diameters are photographed together, and the size of the minimum wire diameter discriminated is measured.

Different x-ray films have different levels of sensitivity, film contrast (gamma values) and graininess.

High-speed x-ray film can be used to photograph small amounts of exposure, but the film contrast and graininess are poor, resulting in poor images in which it is difficult to discern defects. On the other hand, low-speed x-ray film exhibits good film contrast and graininess, resulting in good images in which it is easier to discern defects. However, low-speed film requires more exposure.

Exposure can be reduced by placing the x-ray film between intensifying screens. Three types of intensifying screens are lead foil intensifying screens, metal fluorescent intensifying screens, and fluorescent intensifying screens. The most commonly used type is the lead foil intensifying screen, but the metal fluorescent and fluorescent intensifying screens are used with particularly low-intensity radiation.

To obtain high-quality images in radiographs, one must determine exposure conditions that will yield the proper density.

3-2 Fluoroscopy methods

Fluoroscopy methods commonly employ an image intensifier. The image is photographed at amplified luminosity using a high-resolution image pickup tube (TV camera), and then the x-ray image is displayed on a TV monitor, where it is observed. Fig. 2 shows the construction of an industrial x-ray TV device using an image intensifier.

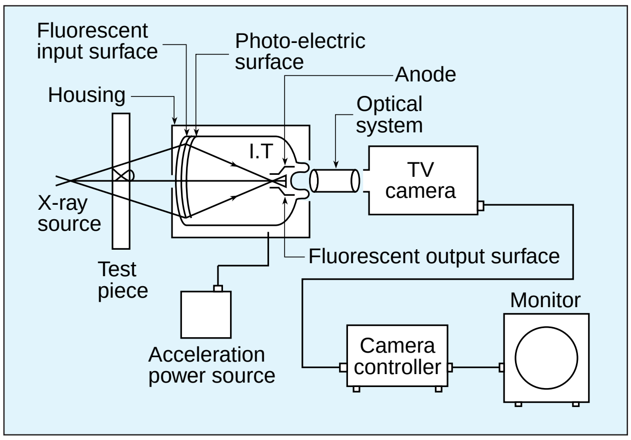


Fig. 2 Construction of an industrial X-ray TV device

The image intensifier in Fig.2 works as follows. The x-rays irradiate the fluorescent input surface, where the x-rays are converted into weak visible rays, and then at the photo-electric surface (which is in contact with the fluorescent input surface) the rays are emitted as photo-electrons. These photo-electrons are accelerated at the acceleration power source and then concentrated by the static electric lens. At the fluorescent output surface, the rays are reduced and become visible images with markedly intensified luminosity. The luminosity intensification ratio reaches several thousand times as bright. When these rays pass through the optical system, they are photographed with the image pickup tube and displayed on the monitor. Some fluoroscopy methods use an x-ray vidicon instead of an image intensifier. The x-ray vidicon has a better signal-to-noise ratio than the image intensifier, but the radiographic field is rather small, making it difficult to use with large test pieces.

Whether defects can be seen with radiation photography depends on the relationship between the size of the ΔD of the contrast showing the defect image and the size of the ΔDmin of the discrimination limit contrast with which the naked eye can see the defect.

Fig. 3 shows the relationship between the defect image width W and the ΔDmin of the discrimination limit contrast. The discrimination limit contrast remains constant in the range with a large width for the defect image, but when the defect image width decreases beyond a certain size, the discrimination limit contrast becomes progressively greater.

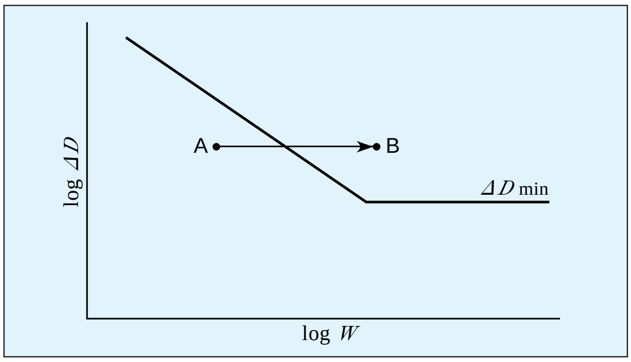


Fig. 3 Improving image quality

Point A in Fig. 3 shows the contrast for a certain width of a defect image. Because this point A is in a smaller range than the discrimination limit contrast, it cannot be discerned. In other words, this represents “an invisible defect”. If we enlarge the defect width at point A to the width at point B, this becomes “a visible defect” which can be discerned. One crucial condition at this time is that the contrast must not be reduced when enlarging the image. Achieving this condition requires x-ray equipment with minute focus, called micro-focus.

Attempting to detect defects smaller than a few dozen microns was difficult with conventional x-ray equipment, which had focus dimensions from 0.4 mm to 2.5 mm. To prevent blurring from the size of the focus in such cases, it was necessary to take the photograph with the test piece closer to the x-ray film, as shown in Fig. 4 (a). However, the ability to use this arrangement with small defects was limited by the defect dimensions unless the contrast could be increased, as Fig. 3 clearly shows.

Fig. 4 (b) shows an example of using micro-focus to detect minute defects. The test piece can be left at the same distance from the x-ray film and the defect can be enlarged without causing image blurring. This is called the enlarged radiographic method.

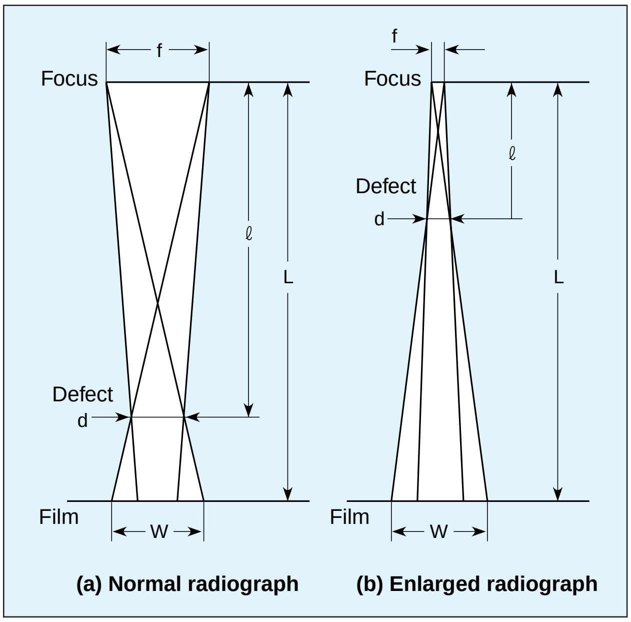


Fig. 4 Normal and enlarged radiographs

To this point, most of the radiographic tests discussed have been those using x-ray film, but some fluoroscopy methods use TV monitors instead of x-ray film. Furthermore, adding image enhancing equipment makes possible such enhancements as integral emphasis and contour emphasis. Using these with enlargement fluoroscopy makes it possible to improve image quality and resolution to the same level as x-ray film. Photos 1 and 2 show examples of such applications.

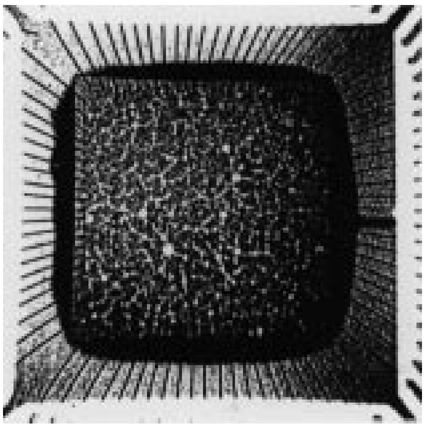


Photo 1 Enlarged radiograph of LSI (about 12×)

Photo 2 Enlarged radiograph of LSI (about 200×)

3-3 Digital method

The digital method uses semiconductors and NaI scintillation detectors for image data, and then reconstructs the images with a computer. Computer tomography (CT) is a typical example of this method. Having gained wide acceptance, CT is often used in medical applications and is also rapidly becoming common in industrial uses as well.

4. Neutron radiography

Thermal neutron rays have absorption coefficients for chemical elements that differ greatly from x-rays. In particular, neutron rays have difficulty penetrating light chemical elements such as hydrogen (H) and boron (B) and specific chemical elements such as cadmium (Cd), tin (Sn), and gadolinium (Gd). As a result, neutron rays can be used for radiography to obtain different information from conventional x-ray and γ-ray radiographs.

Such features of neutron rays can be used for composite materials consisting of a combination of light and heavy elements, for example, testing hydrides covered with materials such as steel or lead, or for testing the bonding condition of metals bonded together.

The following are some areas in which this technology is expected to be used.

(a) Testing nuclear fuels for cracking, unevenness, and damage
(b) Testing processed items, engine nozzles, and electrical parts of all types of rockets for space development, as well as their priming tubes and detonating fuses
(c) Testing all types of aircraft turbine blades for clogging, testing for body corrosion, testing the adhesion condition of the honeycomb structure of the wings, and testing fuel supply tubing
(d) Real time observation of conditions such as fuel supply conditions inside an engine, hydraulic oil inside hydraulic equipment, and hydraulic flow through tubing
(e) Testing all types of new composite materials
(f) Research in medicine and archaeology, such as checking excavated items

The source of neutron rays has conventionally been nuclear reactors and radioactive isotopes. More recently, the development of an easy-to-use small accelerator has led to the wide acceptance of non-destructive testing using neutron rays.

5. Defect detection methods using back-scattering x-rays

To apply x-ray radiographic testing, the test piece must be placed between the x-ray device and the detector (usually x-ray film). Fig. 5 shows the principle for using the defect detection method with back-scattering x-rays. A fine bundle of rays are used for x-ray irradiation without touching the test piece, and the intensity of the scattering x-rays generated to the rear (on the source side) of the test piece is measured. By scanning the test piece, this method can be used to detect defects in the surface layer on the x-ray source side of the test piece. Because the intensity of the scattering x-rays can be measured on the same side as the location of the x-ray source, this method has the special ability to detect defects from a single side, in the same manner as ultrasonic defect testing.

Another aspect of this method deserving attention is that strong back-scattering x-rays, i.e., high-contrast signals, can be obtained even for low-absorption materials with low atomic numbers. This method is suitable for materials with low atomic numbers that could not be detected with radiographic methods, and airport luggage inspections are one typical application for this method.

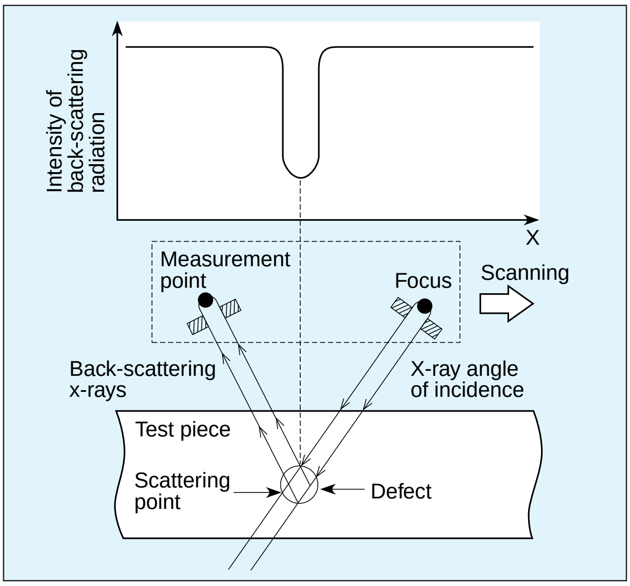


Fig. 5 Principle of back-scattering x-ray defect detection method

6. Infrared thermography

Infrared thermography relies on changes in temperature distribution at the surface of the test piece to detect defect-induced changes in thermal conduction characteristics. Lately, rapid strides have been made in temperature measurement technology using infrared ray transmission, and infrared thermography devices no longer are used merely for macro regions. Equipment has now been developed that is capable of measuring heat in micro regions as small as 10 μm in diameter. These developments are being used to evaluate thermal design of semiconductor components such as ICs and LSIs, as well as to determine acceptance/rejection for temperature distribution from minute joint areas.

7. Ultrasonic testing

The human ear is said to be capable of hearing frequencies in a normal range of 20 to 20,000 Hz (Hertz). Frequencies above the range that can be heard by the human ear are called ultrasonic frequencies. Ultrasonic frequencies can be propagated in materials such as metals just as if from a lighthouse. In other words, ultrasonic frequencies have excellent directional characteristics, and the sound waves travel on a direct path in a tight bundle. Ultrasonic waves traveling on a direct path have the characteristic of reflecting on boundary surfaces such as different objects or gaps. This characteristic can be used to detect defects inside objects, and measure the size and location. Fig. 6 shows the principle of ultrasonic testing.

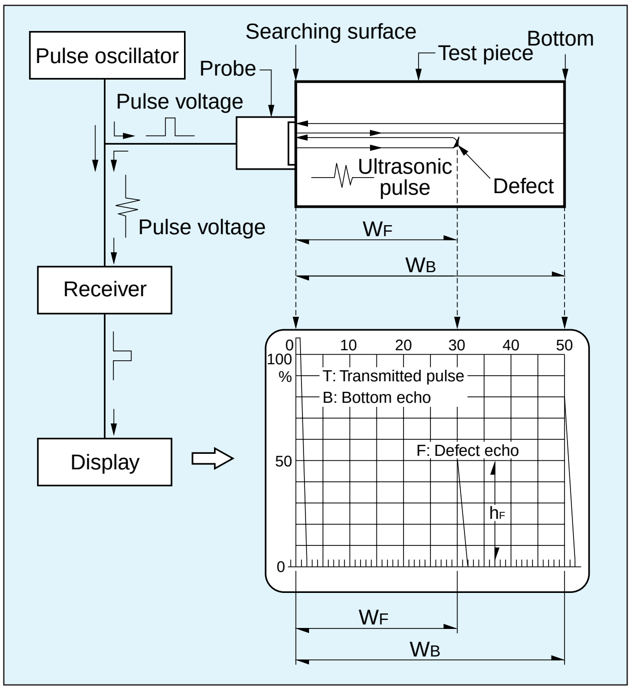


Fig. 6 Principle of ultrasonic testing

8. The ultrasonic microscope

The ultrasonic microscope can be used to test for defects and construction inside materials that could not be detected using optical or electron microscopes. This device can also make quantitative measurements of elasticity characteristics of micro regions.

Defects in materials destroy the strength of materials, cause wear of sliding materials, and cause peeling of coatings and joint surfaces. The Scanning Acoustic Microscope (S.A.M.) is an ultrasonic microscope suited to testing the surfaces of these materials. The S.A.M. focuses an ultrasonic beam at the test surface and mechanically makes a secondary XY scan. Fig. 7 shows an example of this system construction. The heart of the ultrasonic microscope is the ultrasonic focusing element using an acoustic lens at the upper right of the diagram. This is the sensor section. In general, the higher the ultrasonic frequency, the better the resolution, but ultrasonic attenuation increases with penetration into the specimen, effectively limiting the depth that observation is possible. Ultrasonic frequency is applied in a wide range from several dozen MHz to several GHz.

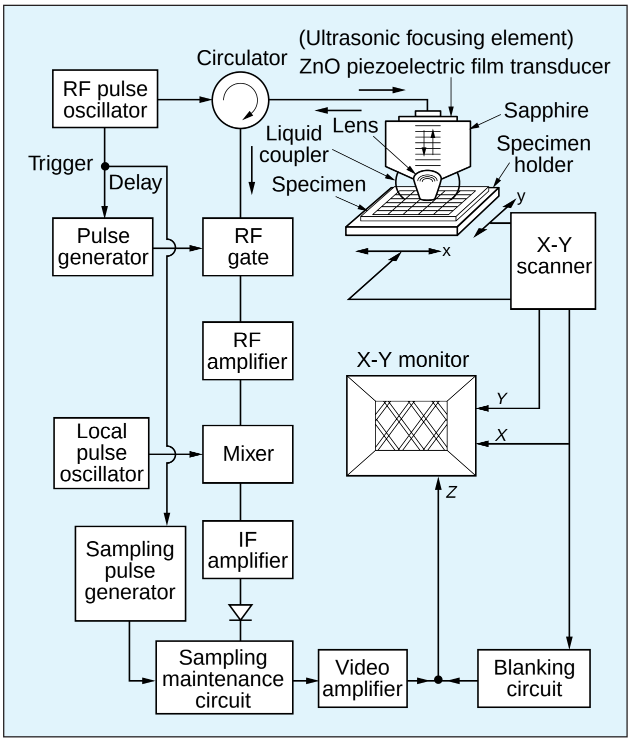


Fig. 7 Construction of mechanical scanning ultrasonic microscope

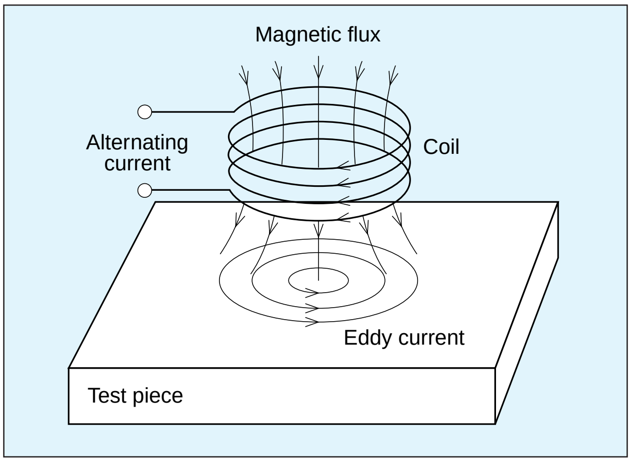


Fig. 8 Induction of eddy current

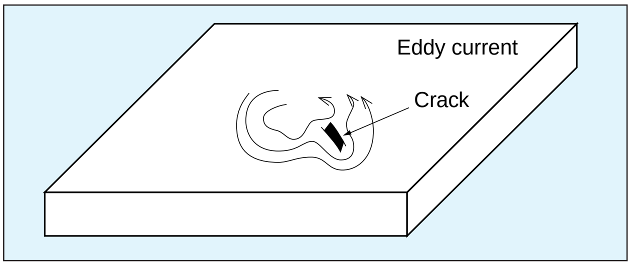


Fig. 9 Changes in the eddy current due to a crack

9. Electromagnetic induction (eddy current) testing

When alternating current is passed through a coil that is near a conductor, electromagnetic induction causes a circular current to be induced in the conductor as shown in Fig. 8. This is called an eddy current.

Eddy current has the property of generating magnetic flux that negates the alternating current magnetic flux of the coil. As seen in Fig. 9, when a flaw such as a crack in the surface of the conductor breaks the succession of the surface, the magnetic flux generated by the eddy current flow changes, and so the magnetic flux in the test coil changes, which appears as a change in the impedance of the test coil. Therefore, defects such as cracks in the surface of the metal can be detected from changes in the electromotive force of the coil.

Eddy current defect testing includes such features as high-speed, non-contact operation and ease of automation.

10. Conclusion

As symbolized by large system accidents these past few years, we are seeing a trend for accidents to create serious social problems. Because of this, the safety of products and facilities is a problem that cannot be bypassed by engineers involved in the field of manufacturing.

Product liability (PL) has become generally accepted to mean that the corporation bears responsibility for results of accidents in which safety is compromised by defects from the design and manufacture of products. Therefore, the importance of non-destructive measurement technology has been rapidly increasing. New research and development in this area can be expected to continue to flourish.

[Bibliography]

1) "Investigative research report on non-destructive testing systems using fine ceramics", p.47, The Mechanical Social Systems Foundation, 1987
2) Ibid., p.41
3) NEC San-ei Instruments, LTD, eds., "Technology Report 106: Infrared emission thermometers"

[Reference books]

1) The Japanese Society of Non-Destructive Inspection, eds., "Introduction to non-destructive testing", The Japanese Society of Non-Destructive Inspection, 1993
2) The Japanese Society of Non-Destructive Inspection, eds., "Manual of new non-destructive inspections", The Nikkan Kogyo Shimbun, LTD, 1992
3) "JIS usage methods series: New manual of non-destructive inspections", Japanese Standards Association, 1995
4) Willie Hammer, "Product Safety Management and Engineering", Kajima Institute Publishing CO.,LTD. 1988
5) The Japan Society for Quality Control, eds., "Quality Assurance and Product Safety", Japan Standards Association, 1994
6) Japan Society of Mechanical Engineers, eds., "Non-destructive measurement technology", Asakura Shoten, 1990

Environmental testing and non-destructive failure analysis technology

Shigeharu Yamamoto*

This report will discuss failure analysis, and the methods of non-destructive failure analysis in particular, as used to improve quality by analyzing the occurrence of failures and providing feedback to the departments concerned. The report will also include some examples of testing and analysis.

1. Introduction

Most manufacturers use environmental testing and failure analysis to maintain quality and reliability of products and parts.

At the developmental stage, environmental testing is carried out to evaluate prototypes under conditions in which the product will be used, or according to test conditions determined by standards. In addition, when product failures occur in the marketplace, environmental testing is done to perform reproducible experiments as a part of failure analysis.

When defects are reproduced through environmental testing, failure analysis is performed to clarify the cause of the failure and the results are provided as feedback to the design or manufacturing processes involved, and countermeasures are then taken. In this way, environmental testing and failure analysis are crucial measures for maintaining and improving product safety and reliability. This report will specifically focus on concrete instances of failure analysis in the first stage, in which non-destructive inspections are especially common. Fig.1 shows an outline of the product im–provement process.

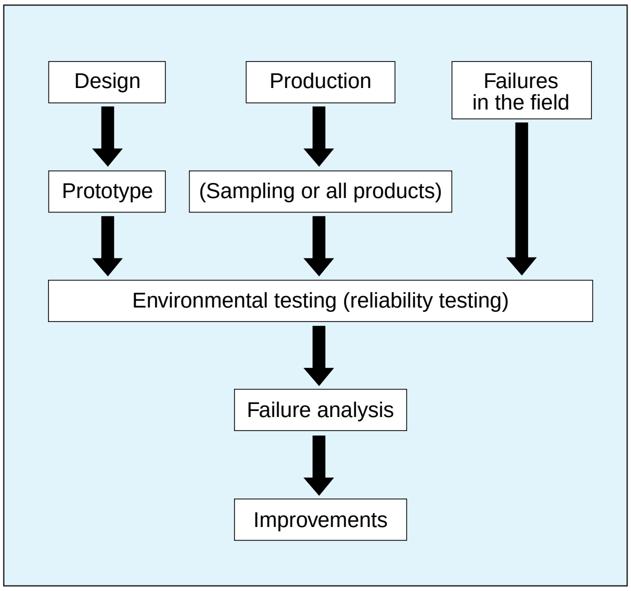


Fig. 1 Requirements for evaluation

*Environmental Test Technology Center

2. Approaches of failure analysis

(1) Even large systems are composed of units and individual subsystems, and those in turn are composed of individual parts, materials, and components that can be analyzed. Failures of these individual parts and materials cause an expanding ripple effect leading to failure of the entire system and causing major accidents. Because of this, reliability is maintained and safety is assured by specifying the causes of these failures and taking countermeasures.

(2) The bigger the system, the more crucial the problems posed by the interfaces between complex parts and units in which hard sections of individual parts and materials are combined with parts and materials of differing qualities. Accidents due to human contributions such as misuse and incorrect operation also form part of this equation. This can be well understood by looking at the recent Donen accident and airplane accidents.

(3) In general the cause of failure is said from experience to be due to:

1. Something that can be handled in design or at the design stage, 80%
2. Something caused in a production process, 15%
3. Something due to usage conditions, 5%

Examples of matters that should be handled at the design stage include (a) constructions that lead to mistakes because the items is difficult to use, cannot be operated easily, or has complex operation, (b) constructions with difficult maintenance such as operations or processes that lead to incorrect operation.

Problems at the design stage are more often due to insufficient design investigation (time/frequency, technology, properly qualified personnel) rather than the design itself.

(4) When failure is very slight, such as only one sample item or one set, product failure analysis looks at whether that failure is likely to have a major impact in the field. Waiting to see whether such failures occur in the field is thought to be too late, and so nowadays quality such as parts, materials, processes, and ease of operation are checked before shipping products to market. A number of examples

are used to illustrate methods for looking in advance at the possibility of incorrect operation or failure, such as advance analysis (good product analysis) in addition to design investigation. One example is the pre-analysis of the inner conductivity conditions of multi-layer PCBs. (Refer to example 6-1.) Failure analysis considers potential and actual failure mechanisms and performs investigative research to provide corrective measures. These corrective measures can also be applied to other situations. When a failure occurs due to some cause, that cause can be identified as physical, chemical, mechanical, or electrical, or as due to human error. The results can always be explained in terms of the failure being caused according to a particular development.

3. *Methods of failure analysis*

Failure analysis can be broadly divided into destructive and non-destructive testing. Potential defects and actual failures are identified and confirmed, and electrical, physical, chemical, and human engineering investigations are undertaken. These activities are crucial to creating countermeasures for the causes of failure. Fig. 2 shows the general procedure for failure analysis.

Two methods of locating failure are:

(1) The overall method {epidemiological method: non-destructive testing}, and

(2) The individual method {epidemiological method (physical failure method): destructive testing}.

For procedure, less time is lost by taking up the epidemiological method first and the physical failure method later.

An unexpectedly large number of failures can be found with the epidemiological method, but when the epidemiological and epidemiological methods are skillfully combined, reliability can be greatly improved.

(1) The epidemiological method

This approach uses statistics to explain the degree of failure (e.g., according to time, place of occurrence, market distribution, market location, distribution of usage conditions, distribution of users, by lot, and time differences in manufacturing methods). Even if the reason for this type of failure is not understood, the range encompassing the failures can be narrowed down, and has the know-how to come up with effective countermeasures.

This method can be used by anyone with no need for expensive equipment.

(2) The epidemiological method (physical failure method)

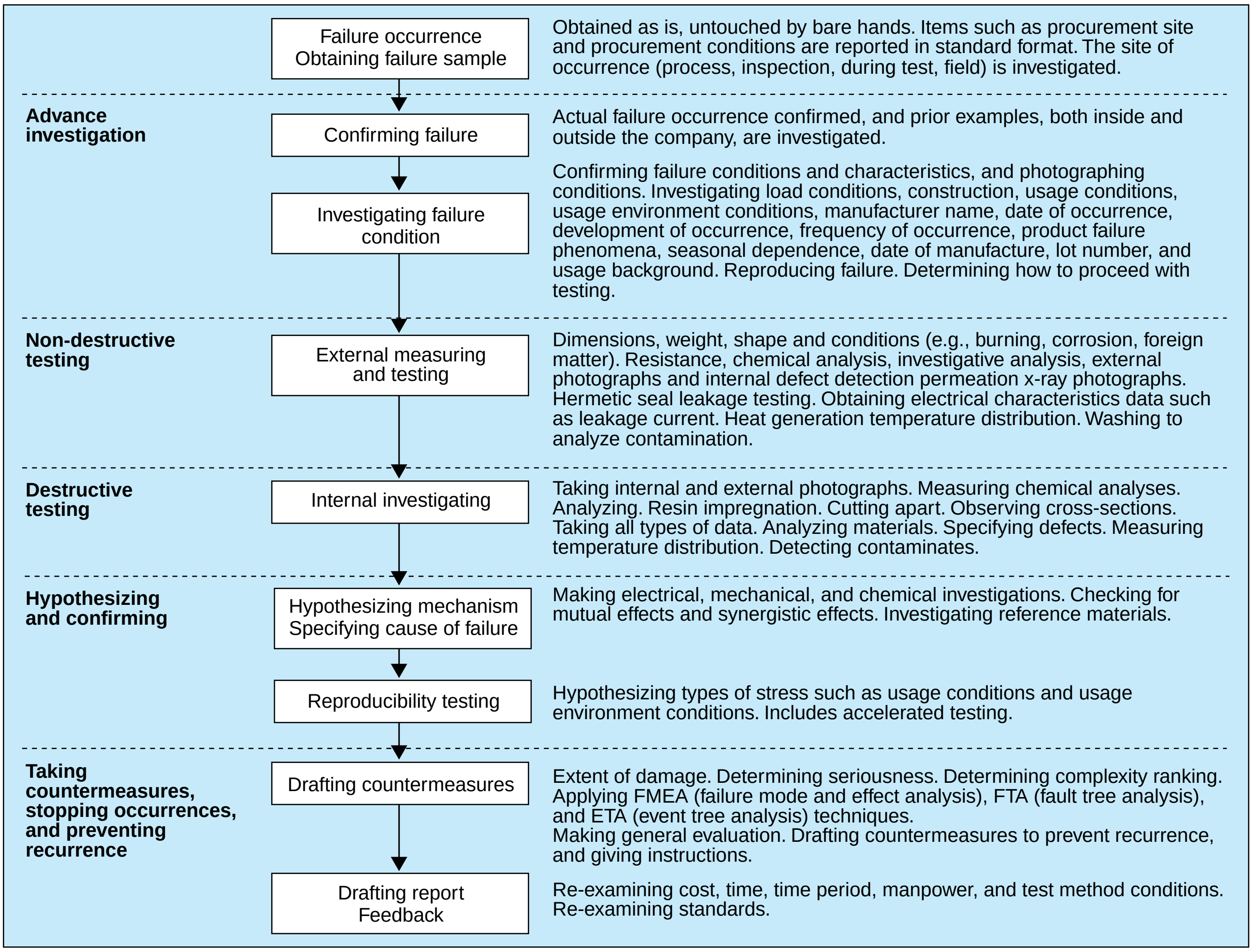


Fig. 2 Example of failure analysis

This approach relies on completely grasping the mechanisms and principles of the failure and narrowing the actual cause to one point. In other words, this method has the know-how to theoretically understand why the failure occurred.

Failure analysis clarifies the cause of failure, understands the failure mechanism, and links these to preventing recurrence of failure.

In failure analysis, it is vital to obtain as much information as possible externally before making a destructive investigation, and normally non-destructive testing is done first. The extent of information obtained from this non-destructive testing will greatly influence later analysis and countermeasures.

When performing failure analysis, the following specific items must be considered.

1) Don't analyze with insufficient investigation into factors such as shipping conditions, usage conditions, and usage environmental conditions.
2) Don't handle failure samples carelessly.
3) When investigating appearance, look at such conditions as dimensions, thickness, weight, shape, bending, color changes, rust, foreign matter adherence, mold, cracking, scratching, cloudiness, scorching, and nicking.
4) Since destructive analysis will cause the original shape and conditions to be lost, be sure to take plenty of pictures at the initial stage from every angle, of the piece as a whole, and with enlargements.
5) Carefully observe and record each time.
6) Since failure analysis uses tools and chemicals, consider worker safety.
7) Analyze failure objectively. Don't become convinced that a particular idea must be true.
8) Since the human factor is an important cause, consider the background carefully.
9) Analysis relies greatly on experience, skill, and power of observation.
10) It is dangerous to ignore multiple causes and become convinced of a single cause.
11) Don't destroy the object by overloading.
12) Compare failed items with good items, and analyze the failures.
13) Consider effects from the workers themselves and from jigs, tools, and equipment used.
14) Don't throw away the specimens before final results have been attained. Keep them.
15) When making judgements, don't simply use the data alone as if it were analysis results.
16) Prepare good items from the same lot as the failed items. When the cause of failure is suspected to run across lots, good items must be investigated together across lots.
17) As a rule, proceed from the general situation to details to the overall picture. Also, go from external to internal analysis, from peripheral to the object, and from non-destructive to destructive.
18) Make full use of such elements as knowledge, experience, and data. Ask for assistance from another specialist.
19) In failure analysis, when you have gone on to the next process, you can't go back, so you must observe very carefully at each stage of analysis.

4. *Types of non-destructive test equipment*

Table 1 shows examples of widely-used non-destructive tests that are low-cost and generally very easy to procure.

Table 1 Examples of non-destructive test equipment

	Name	Cost	Usability	Applications, other
1	**Microscope (optical microscope)**	Relatively inexpensive	Easy to use	Having a monitor is a plus. Even better if dimensions can be measured on the monitor.
2	**Metallurgical microscope**	Relatively inexpensive	Easy to use	Same as above
3	**Scanning acoustic (ultrasonic) microscope (SAM)**	Expensive	Relatively difficult to use	Can be used to see internal defects (e.g., voids, cracking, contamination) and interface conditions
4	**Scanning electron microscope**	Expensive	Relatively easy to use	High magnification photographs (particularly, above 1000×)
5	**Ultrasonic flaw detector (SAT)**	Relatively inexpensive	Easy to use	Same as above
6	**Soft x-ray apparatus**	Expensive	Easy to use	Same as above
7	**Ultraviolet flaw detector**	Inexpensive	Easy to use	Minute surface cracking, pitting, or flaws
8	**Red check**	Inexpensive	Easy to use	Same as above
9	**Calipers, micrometer**	Inexpensive	Easy to use	Checking dimensions and thickness
10	**Multimeter**	Relatively inexpensive	Easy to use	E.g., watts, resistance, and current
11	**Thermography**	Expensive	Relatively easy to use	Measuring abnormal surface temperature distribution
12	**Magnifying lens (5× or less)**	Extremely inexpensive	Easy to use	Overall external observation
13	**Magnets, lighters, and so on**	Extremely inexpensive	Easy to use	Checking whether magnetic, whether easily flammable, whether heat resistant
14	**Precision cross-section cutter**	Medium price	Easy to use	Cutting cross sections of materials and parts

(Cont.)

(Cont. from the previous page)

	Name	Cost	Usability	Applications, other
15	**Resin filler**	Extremely inexpensive	Easy to use	Resin filling of items such as cross-sectioned parts and materials, and for resin filling before cross-sectioning
16	**Polisher**	Medium price	Easy to use	Polishing resin filled items and inspection items
17	**Temperature and humidity chamber**	Medium price	Easy to use	Specimen reproducibility testing
18	**Ultrasonic cleaner**	Comparatively inexpensive	Easy to use	Washing specimens
19	**Close-up photography equipment**	Medium price	Easy to use	Photographs of specimens from every angle for analysis and evidence
20	**Thermocouple thermometer and digital thermometer**	Comparatively inexpensive	Easy to use	Measuring temperature and measuring temperature rise

Adding the latest equipment to the above yields dozens of types with prices ranging from several hundred thousand yen to tens of millions of yen.

In internal inspection, equipment such as soft x-ray apparatus is easy to use and has a wide range of applications, and so is widely used. With the acquisition of experience comes the ability to spot specific failure sites and guess the general source of the problem without spending any money.

5. *Objectives of environmental tests and the affects of tests*

Table 2 shows the relationship between test conditions and the objectives of environmental tests and the affects of test when testing with environmental test equipment.

Table 2 Examples of test conditions and the objectives of environmental tests and the affects of tests

Environmental test		Objectives	Affects	Examples of typical test conditions, other
Temperature	**Low temperature resistance**	Investigates the low temperature resistance of electronic parts and equipment, and the low temperature storage characteristics. Looks at volume expansion and degradation of characteristics due to freezing, degradation of functions and performance, and mechanical characteristics caused by contraction.	Thermal and mechanical deformation due to expansion and contraction. Promotes softening and brittleness, loss of lubrication characteristics, sealing, cracking, and freezing of liquid portions of the specimen.	From –85°C to room temperature Temperature distribution: from ±0.5 to ±1°C Programmed automatic operation
Temperature	**High temperature resistance**	Investigates temperature-related changes in electronic parts and equipment. When there is an active element, usually it is activated or supplied with electricity at high temperatures and degradation of characteristics is examined. Looks at degradation of lubrication characteristics.	Promotes chemical reactions such as oxidation and diffusion. Expansion, softening, evaporation, oxidation, lowered viscosity cracking, diffusion, and leaking.	From room temperature to 300°C Temperature distribution: ±0.5 to ±1°C Programmed automatic operation
Temperature	**Temperature cycle**	Investigates thermal stress in electronic parts and equipment. Used for screening parts for automotive and aircraft applications. Accelerates usage environments.	Distortion due to expansion and contraction, peeling, cracking, cracking due to liquid evaporation, fatigue, cracks in finished surface, and changes in electrical characteristics due to mechanical displacement.	From –65°C to +150°C Programmed automatic operation
Temperature	**Thermal shock**	Evaluates affects of thermal stress in a short time period by using liquid with a large thermal capacity. Looks at such factors as dimension changes due to differences in coefficients of thermal expansion, and accompanying changes in specimen characteristics and adhesion, evaluation of terminal sealed sections.	Cracking of molded parts, peeling, mechanical deformation, and other factors roughly the same as above.	From –65°C to +150°C Specimen movement, 5 seconds Programmed automatic operation
Humidity	**Humidity resistance**	Investigates degraded characteristics due to humidity in electronic parts and equipment. Evaluates humidity absorption characteristics of insulation materials, storage, and dry characteristics at low temperatures.	Insulation loss, promotion of corrosion and electrolytes, condensation, expansion, increased leak current, deformation, changes in characteristics, bending	From 85% RH to 95% RH From 10% RH to 40% RH Programmed automatic operation
Humidity	**Humidity cycle**	Acceleration of such factors as condensation and humidity absorption characteristics, and other factors roughly the same as above.	Respiratory effect, dew condensation, freezing, ionic migration.	From 40°C to 80°C From 20% RH to 95%RH

Environmental test	Objectives	Affects	Examples of typical test conditions, other
Dew cycle	Evaluates parts, materials, and equipment for thermal shock resistance while at the same time evaluating changes in characteristics due to condensation occurring concurrent with changes in temperature and humidity.	Ionic migration, corrosion, shorting, insulation defects, and film peeling	From –35°C to +85°C From 60% RH to 90% RH Transfer time, 5 seconds Temperature stabilized, 20 seconds
HAST (PCT)	Accelerated testing of thermal resistance characteristics. Looks at effects of humidity penetration and distribution	IC mold cracking, sealing defects, seal peeling, adhesion characteristics, deformation, corrosion, insulation degradation, cracking, adhesion peeling	125°C at 85% RH (121°C at 100% RH) Both saturated and unsaturated tests possible
Air pressure	Looks at such characteristics as ability of parts, materials, and units to withstand voltage in altitude, vacuums, and high pressure.	Degradation of electrical ability to withstand pressure, sealing (hermetic) defects, degradation of life of contact points, changes in dielectric constants of materials, changes in thermal conductivity, and degradation of insulation.	From 133 Pa to 10 kPa
Salt mist	Accelerated testing of rust and corrosion and anti-corrosion characteristics of leads on electronic parts, and evaluation of coatings, paint films, and platings.	Corrosion, rust, insulation degradation, increased contact point resistance, peeling, deformation.	35°C, 5% NaCl 35°C, dry, moist
	Some items can be tested with the CASS (copper accelerated acetic acid salt spray) test. 50°C, 5% saltwater + cupric chloride + glacial acetic acid		
Weathering test	Looks at degradation of products and materials due to ultraviolet rays and other radiation. (Paint coatings and plastics)	Fading colors, weakness, cracking of high molecular materials, deformation, sealing defects	Equivalent to the sun's rays
Combined environment of organic gases H_2S/SO_2	Accelerated testing to evaluate the corrosion resistive environmental characteristics of leads and metal parts by corrosive gases in atmospheric pollution or emitted from the materials	Effects from such sources as corrosive gases, such as corrosion, rust, insulation degradation, defective contact, wire disconnection, increase in contact resistance	Simple or compound gases SO_2, H_2S, NO_2, Cl From 0.01 ppm to 100 ppm
Acid rain	Looks at the affects of acid rain	Same as above	From 4 to 6 pH
Dust and sand	Looks at degradation of functions and characteristics due to cracking and infiltration-induced contact defects in contact parts and moving parts. Checking hermetic seal, insulation, and corrosion.	Malfunctioning, corrosion, surface wear, clogging, charging, insulation degradation, wear, leakage	Sand, fiber, dust
Ozone	Looks at ozone-induced degradation of characteristics of parts, materials, and products.	Deformation, cracking, oxidation, and weakening of organic materials	From 0.01 to 20 mg/m^3
Vibration	Used for fatigue testing of electronic parts and vibration experiments on products. Also, for the same purposes, looks at structural strength with respect to vibration during shipping and handling of packaged electronic parts, materials, and equipment.	Mechanical looseness, fatigue destruction, wire disconnection, damage due to harmonic vibration, defective socket contact, joint wear, destruction due to harmonics, lead breakage, occurrence of noise and abnormal vibration, cracking	From 2 to 2000 Hz 588 m/s^2
Shock	Looks at mechanical strength due to shock with respect to the same problems noted above.	Same as above	98 to 9806 m/s^2 / 1 to 60 ms
Bump	Looks at parts, materials, and products for strength against fatigue received during shipping.	Same as above	392 m/s^2, 6 ms, 196 m/s^2/11 ms
Tensile and bending	Looks at mechanical strength of products and materials in such areas as stretching.	Disconnecting, breaking, deformation, short circuits, stretching	One time or repetitive
Mold	Looks at factors promoting mold and changes in characteristics of materials due to mold	Insulation degradation, short circuits, corrosion, oxidation, erosion, contamination, and degradation of optic system transmissivity	—
Soldering heat resistance	Looks at resistance of electronic parts to solder, strength and heat resistance characteristics, and connectivity.	Solder cracking, looseness of terminal windings, changes in thermal characteristics of parts, softening of insulation materials, deformation	From 200°C to 400°C
Charging, electromagnetic induction, static electricity	Looks at static electricity-induced damage in dry environments, resistance of electronic parts and equipment to static electricity, noise margin resistance characteristics, and relay life evaluation	Radio wave interference, destruction of insulation, adherence of foreign matter, malfunctioning, damage to semiconductors and other parts, operation stoppage, runaway	From 10 kV to 30 kV

HAST: Highly Accelerated Temperature and Stress Test   PCT: Pressure Cooker Test   I.M.: Ionic migration

Photos 1 through 3 show typical environmental test equipment currently in wide use.

(1) Photo 1: HAST (PCT) Chamber

Pressure is raised from a minimum of 1 atmosphere, and specimens are placed in the temperature and humidity conditions of the test area. Parts and materials are evaluated for humidity resistance characteristics and insulation characteristics under highly accelerated conditions. Care must be taken with the maximum permissible temperature of the specimens.

Photo 1 HAST Chamber (Highly Accelerated Stress Test Chamber), product of Tabai Espec

(2) Photo 2: Thermal Shock Chamber

This product is used to effectively evaluate changes in thermal expansion coefficients that are deeply connected to problems in such areas as connections, seal performance, thermal characteristics, inherent stress from manufacturing, compound materials in parts such as molded parts, and mold processing in parts such as ICs. Both liquid phase and gas phase tests are possible, but since liquid phase tests are much more accelerated than gas phase tests, the liquid phase is particularly widely employed for testing parts and materials.

Photo 2 Thermal Shock Chamber (product of Tabai Espec)

(3) Photo 3: Temperature and Humidity Chamber

This is a very widely used tester that maintains constant humidity at both low and high temperatures for all items, and performs combined temperature and humidity (cycle) tests. Industrial water and tap water must not be used in these tests, as they contain contaminants such as minerals and disinfectant chlorine that affect the samples.

Photo 3 Temperature (& Humidity) Chamber, Platinous K Series (product of Tabai Espec)

6. Examples of non-destructive tests

6-1 Example 1: Analysis of non-defective multi-layered PCBs

Multi-layer printed circuit boards use internal wiring and holes called via to make connections between the layers. (These holes are used exclusively for connecting between layers and are not used for installing parts.) Connections are made through all of the layers using holes called by such terms as “through holes”. If the relative positions of the wiring of each layer is not within tolerance, processing will cause such problems as short circuits and broken wiring, and so these holes must be inspected and screened before processing. Based on the results of inspection using a soft x-ray apparatus, determination is made on whether the relative positions are within tolerance. (Photo 4)

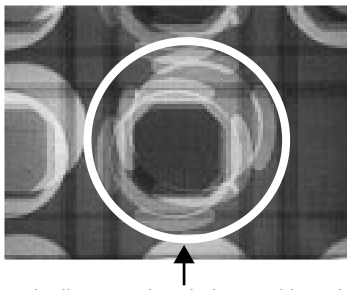


Photo 4 Example of defect analysis of multi-layer PCB (photographed with Softex SFX-70)

6-2 Example 2: Broken wire on temperature sensor (production equipment)

The continuity of the internal temperature sensor had to be investigated when it became impossible to control the temperature. The results of an inspection using a soft x-ray apparatus showed a broken connection at a welded joint on the thermocouple sensor tip. (Photo 5)

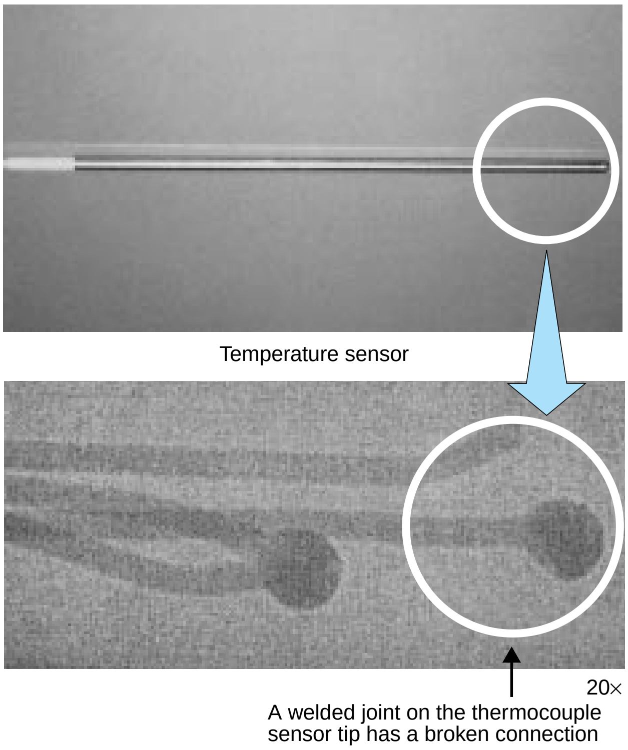


Photo 5 Example showing a broken connection in a temperature sensor (photographed with Softex PR-TEST 100)

6-3 Example 3: IC chip adhesion defect

Internal IC conditions needed to be investigated due to degradation of IC characteristics and mold peeling and cracking. The results of an inspection using a soft x-ray apparatus showed that an air layer (the white section in Photo 6) had developed between the chip and the base due to defective adhesion.

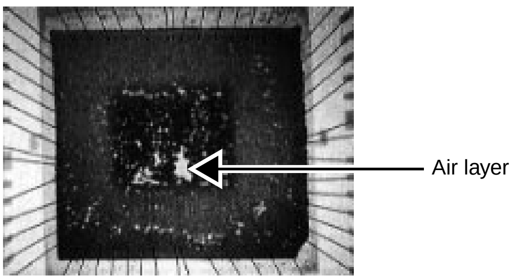


Photo 6 Example of IC chip adhesion defect

6-4 Example 4: Broken connection on sheathed heater (production equipment)

The internal portion of a sheathed heater had to be checked when the temperature inside a chamber would not rise. The results of an investigation using a soft x-ray apparatus showed a broken connection in the heater element. (Photo 7) In addition, an inspection of the external appearance showed corrosion on the stainless steel heater protector tube, with water invading the heater through the corroded section and causing a short resulting in a broken connection.

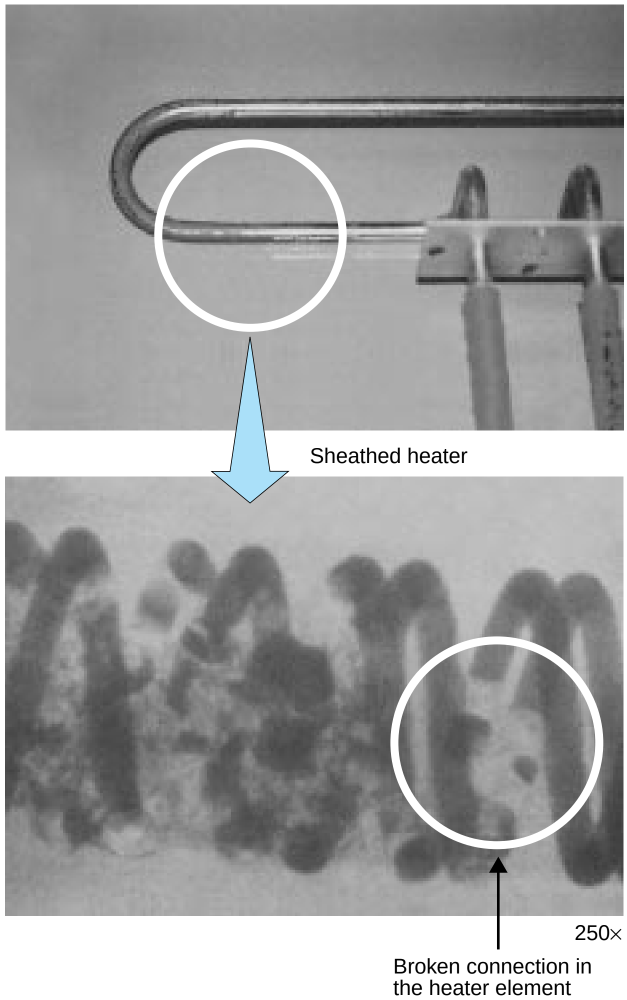


Photo 7 Example of a broken connection in a sheathed heater (photographed using Softex PRO-TEST 100)

6-5 Example 5: Defective connection in a BGA solder ball

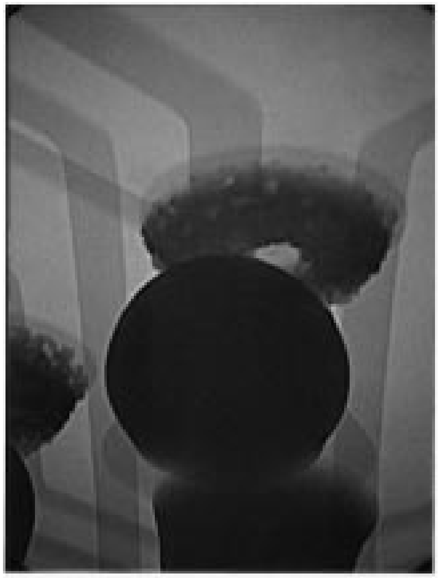


Photo 8 Example of defective connection in a BGA solder ball (photographed using Marubun Corporation EV-160 ml)

Through the use of third generation photography, the BGA ball was shown to be floating.

6-6 Example 6: Lift-off of Pb-free solder

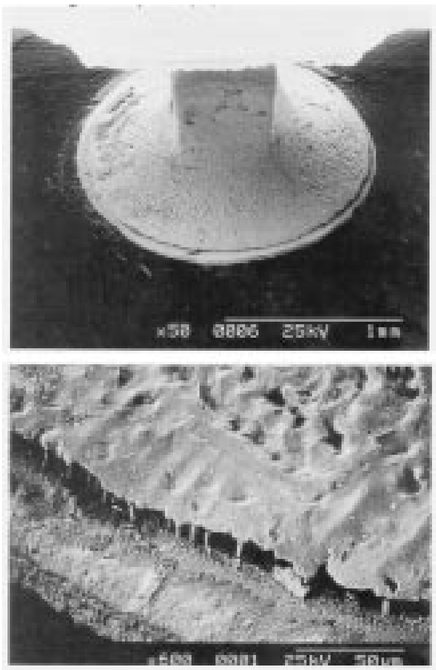


Photo 9 Example of lift-off of Pb-free solder (photographed using Hitachi S-2300)

Occurs in the initial soldered condition.

[Bibliography]

1) Reliability Engineering Association of Japan Edition, “Reliability Handbook”,1997

2) Commercial Affairs Office, Industrial Policy Bureau, Ministry of International Trade and Industry, “Report on accidents infomation collecting system in 1998”, National Institute of Technology and Evaluation, Ministry of International Trade and Industry, 1999

3) “X-ray Image TV System”, SOFTEX

Report 1

The affects of adsorbed water on printed circuit boards, and the process of ionic migration

Hiroko Katayanagi* Hirokazu Tanaka* Yuichi Aoki* Shigeharu Yamamoto*

*This report considers the insulation resistance characteristics of printed circuit boards (PCBs) and the effects of ionic migration in environmental testing. By measuring insulation resistance in a variety of environmental test conditions, the authors have determined that the initial changes in insulation resistance values is caused by water adsorption*1 and electrolysis. While investigating the occurrence of ionic migration, the authors were able to confirm that metal ions eluted in response to changes in the pH near the electrodes. These changes in pH were determined to have been caused by the electrolysis of water, which affected both pH and applied voltage.*

1. Introduction

In recent years, the trend toward compact and lightweight electronic devices has been accompanied by crucial problems in insulation reliability. Such reliability problems have been particularly noticeable with ionic migration (IM).

To properly evaluate the insulation reliability of PCBs during environmental testing, standards have been set for insulation resistance measurement in high-temperature, high-humidity tests. (Table 1)[1] These standards consist of applying flux and solder paste on prescribed electrodes and evaluating (1) the diffusion of water absorption in the flux and the resin base material, and (2) the time elapsing in the progress of the insulation deterioration due to the reduction effect of metal ion elution caused by the electric field coming from the applied voltage.

The insulation resistance values seen in environmental tests appear as a result of IM caused by (1) electrolysis due to moisture adhering to the surface of the PCB and its adsorption, and (2) by the elution and diffusion of metal ions, and their subsequent reduction. (Photos 1 and 2)

This report points out the correlation between IM and the changes in insulation resistance due to the adsorption of water. By running actual environmental tests and analyzing the IM mechanism, the authors noticed the following relationships between IM and insulation resistance values:

(1) Insulation resistance characteristics and the adsorption of water during environmental tests,
(2) Characteristics of changes in current due to the electrolysis of water,
(3) Changes in pH in the vicinity of electrodes and the elution of metal ions, and
(4) The affects of pH on the occurrence of IM.

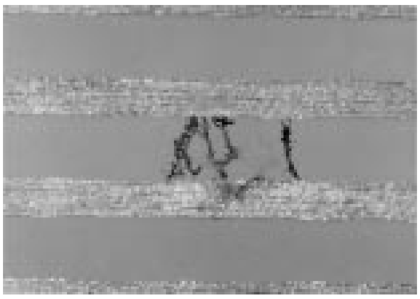


Photo 1 Dendrites occurring on a glass epoxy PCB (60×)

Table 1 Main standards for evaluating insulation resistance

Standard	Test name	Test conditions	Applied voltage	Measurement voltage
1. ANSI-J-STD-004	Requirements for Soldering Fluxes	85°C, 85% RH, 168 h	50 V DC	100 V DC
2. JIS-Z-3284 Appendix 14	Solder paste	40°C, 90 to 95% RH, 1,000 h	45 to 50 V DC	100 V DC
		85°C, 85 to 90% RH, 1,000 h		
3. IPC*-TM-650-2.6.3	Moisture and Insulation Resistance, Printed Boards	35°C, 85 to 93% RH, 4 days (class 1)	100 V DC	Decided in consultation with purchaser.
		50°C, 85 to 93% RH, 7 days (class 2)		

*IPC=The Institute for Interconnecting and Packaging Electronic Circuits

*Environmental Test Technology Center

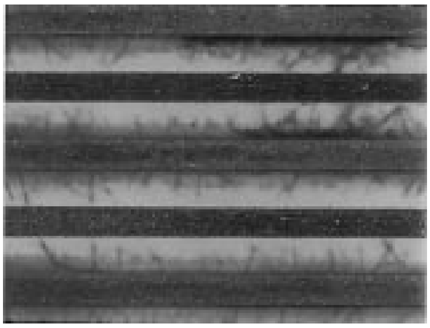


Photo 2 Example of paper phenolic board and CAF* throughout substrate material

* CAF = Conductive Anodic Filaments

2. *Water adsorption and insulation resistance characteristics during environmental tests*

Changes in PCB insulation resistance values during environmental tests is intimately related to the amount of water adsorption. These experiments measured both PCB resistance values and changes in the amounts of moisture absorbed under high-temperature, high-humidity test conditions. Table 2 shows the test conditions.

Table 2 Insulation resistance test conditions

Item	Details
Test conditions	3 sets of conditions: 40°C, 87% RH; 60°C, 87% RH; 85°C, 85% RH
Applied voltage	50 V DC
Measurement intervals	Every hour (measurement voltage = 50 V DC)
Specimen	Copper-clad glass epoxy (FR-4) Conductor intervals: 0.318 mm (JIS type 2)

Fig. 1 shows the insulation resistance characteristics during high-temperature, high-humidity tests. The specimens are glass epoxy PCBs with JIS type 2 copper electrodes. Measurements consisted of applying 50 V DC after the temperature and humidity had stabilized for 24 hours, and measurements were recorded hourly using an insulation resistance continuity tester. (Photo 3 shows an ionic migration evaluation system.) Fig. 1 shows a sharp rise in insulation resistance values in the initial stage of the tests, changing to a roughly stable condition after the passage of a specific amount of time. During the stable period, the insulation resistance values showed a tendency to become increasing lower in response to more severe temperature and humidity conditions.

Fig. 2 shows humidity absorption characteristics. Humidity absorption was measured by exposing the specimens to 100°C for 24 hours, then taking the initial value of the absolutely dry weight, and then measuring the weight every hour and finding the change according to the following formula, which compares the absorption weight of the PCB with its initial weight.

Change (%) in humidity absorption weight

$$= \frac{\left(\begin{array}{l}\text{weight after}\\ \text{humidity absorption}\end{array}\right) - (\text{initial weight})}{(\text{initial weight})} \times 100$$

The humidity absorption of the PCB shows a sharp increase in the initial period, followed by a gradual increase. The results also confirmed that the humidity absorption of the PCB during the environmental tests corresponded to temperature and humidity conditions.

The adsorbed water is dispersed within a solid object due to the water molecules being dispersed in the intermolecular intervals of the solid.[2)] Therefore, changes in the humidity absorption rate can be hypothesized as due to such factors as the amount of water adsorbed into the interior of the solid, the diffusion weight, and the diffusion time, and can be conjectured to be determined by the PCB materials and environmental conditions.

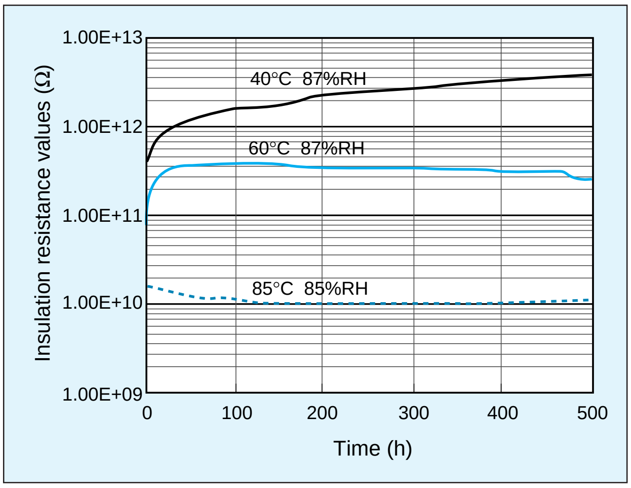


Fig. 1 Insulation resistance characteristics during environmental tests

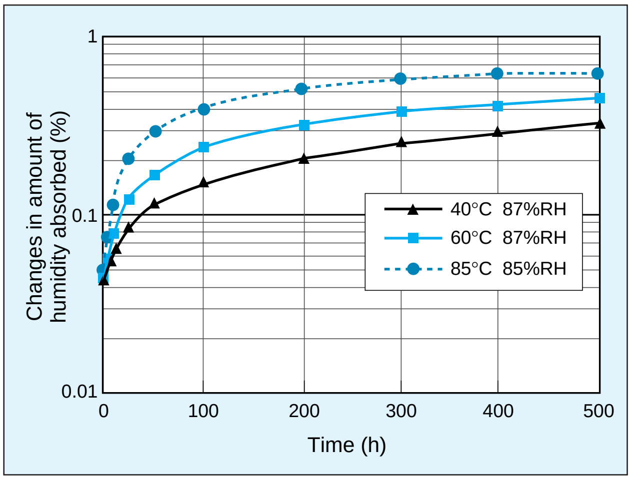


Fig. 2 Humidity absorption characteristics during environmental tests

Photo 3 Ionic migration evaluation system

3. *Verification experiments*

3-1 Electrical current characteristics resulting from the electrolysis of water

To find the characteristics of electrical current resulting from the electrolysis of water, the following type of verification experiments were carried out at room temperature. In these experiments, teflon PCBs (0.318 mm conductor intervals) with metal-plated electrodes were used to prevent water being absorbed by the PCB*2, and to prevent corrosion of the electrodes. One µL of ion-exchange water (conductivity = 2.5 µS/cm, measured pH = 6.6) was dripped between the electrodes (Fig. 3), and the elapsed time changes in electrical current were measured. Fig. 4 shows the changes in electrical current characteristics caused by the electrolysis of water when water is adsorbed on the surface of the electrodes.

The electrical current cannot be measured with a maximum applied voltage of 1 V DC, presumably because electrolysis did not occur, since the theoretical decomposition voltage of water is 1.23 V.[3)]

The trends exhibited by the electrical current characteristics included (1) rising within a few seconds, and then (2) gradually dropping, and finally (3) stabilizing.

During the initial period of voltage application, the following events occur. (1) H+ and OH- ions from water ionization quickly collect around the electric double layer*3 on the surface of the electrodes, and so the current flows rapidly. (2) Next, due to the electrolysis of water, metal ions gradually elute in the vicinity of the electrodes, and an increase in ion concentration around the electrons causes a drop in metal ion exchange and in levels of electric current around the electrodes. (3) Then, when the concentration of these ions surpasses that of metal ions, the elution and reduction of the metal ions attains equilibrium, and so the electrical current stabilizes.[4)] When stabilized, water exhibits electrical resistance, and so electrical current can be presumed to depend on applied voltage.

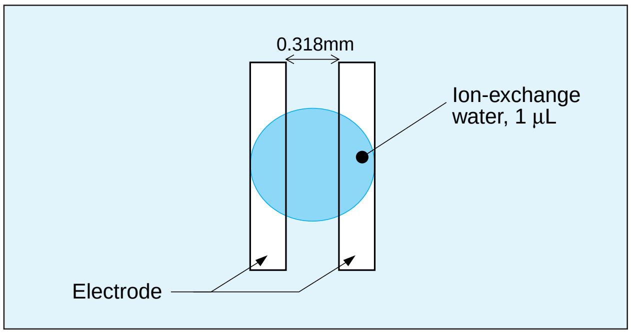


Fig. 3 Experiment conditions

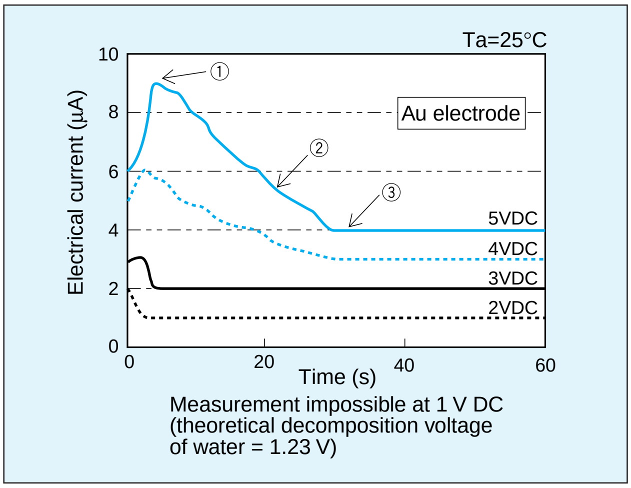


Fig. 4 Electrical current characteristics resulting from the electrical decomposition of water

These experiments concern short-period water adsorption and electrolysis, but the results of the experiments shown in Fig. 1 and 2 indicate that even during environmental testing, electrolysis of the absorbed water occurs gradually during the initial period. We can hypothesize the following process. As the elution of the metal ions begins, insulation resistance values change from low resistance to high resistance. Before long, when water adsorption becomes saturated, the elution and reduction of the metal ions reaches equilibrium, and so exhibit stabilized resistance values.

3-2 Changes in pH near the electrodes, and elution of metal ions

Based on the assumption that the electrical current characteristics are related to the elution of metal ions, these experiments regarding metal ion elution were repeated at room temperature.

Fig. 5 shows the relationship between applied voltage and the amount of metal ion elution. One µL of ion-exchange water was dripped between the electrodes of a copper-clad glass epoxy PCB (conductor intervals, 0.318 mm) and the amount of copper ion elution was measured using test sticks for the semiquantitative determination of copper. The results indicated that the amount of copper ion elution corresponded to the applied voltage.

Changes in the pH near electrodes caused by the above-noted test method were also measured using pH test paper. The pH in the vicinity of the electrodes when the applied voltage was a minimum of 2 V DC were: at the anode, acidity with a maximum of pH = 3; at the cathode, alkalinity with a minimum of pH = 10. (Fig. 6) The following reaction formula[4] can be hypothesized.

Cathode: $4H_2O + 4e^- \rightarrow 2H_2 + 4OH^-$ (alkaline)

Anode: $2H_2O \rightarrow 4H^+ + O_2 + 4e^-$ (acid)

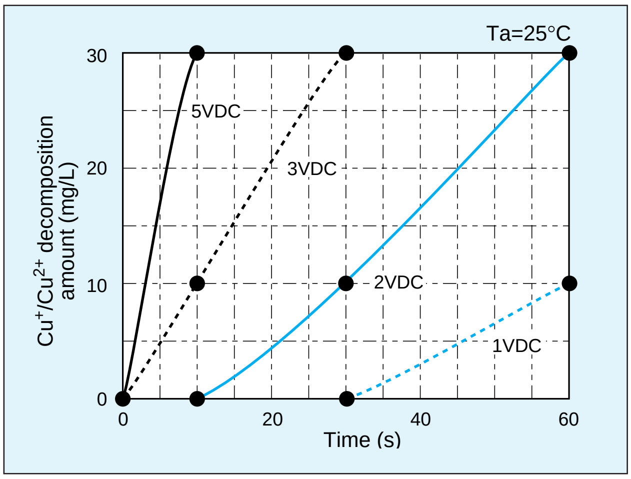


Fig. 5 Quantitative characteristics of elution: voltage and copper ions

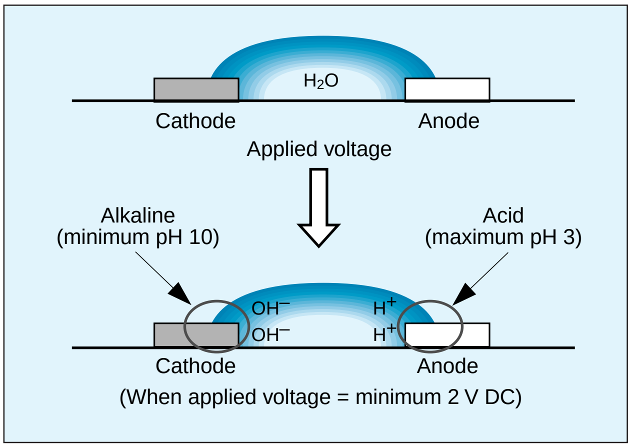


Fig. 6 Changes in pH in the vicinity of the electrodes

The surface of the copper is covered with a film of matter oxidized in the air (a compound of Cu_2O and CuO), and resists corrosion.[5] However, this substance exhibits copper ion elution in acid and alkaline solutions. Fig. 7 shows electric potential vs. pH using an equilibrium diagram according to Pourbaix.[6] From this graph, we can see that pH changes with the application of voltage result in the elution of Cu^{2+} on the acid side and CuO_2^{2-} on the alkaline side. Therefore, we can postulate that the electrolysis of water causes hydrogen ions form on the anode and hydroxyl ions to form on the cathode[7], and that the film of oxidized matter on the surface of the copper is dissolved due to changes in pH in the vicinity of the electrodes, and copper ion elution is accelerated.[5]

The standard electrode electrical potential of the metal copper dissolves in solution, Cu^{2+} at + 0.337 V (Vs.SHE*5), and Cu^+ at 0.520 V (vs.SHE). As a result, copper ion elution occurs even at around the minimum

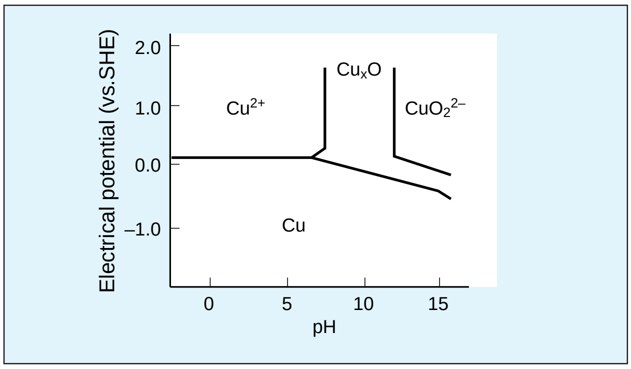


Fig. 7 Potential-pH equilibrium diagram for the system copper [6]

theoretical voltage for the electrolysis of water, but the higher the voltage, the greater the amount of copper ion elution.

From the above considerations, we can assume that applied voltage and water adsorption are accelerating factors for the elution of metal ions from PCBs during environmental tests.

3-3 Diffusion and reduction of eluted metal ions

The diffusion and reduction of the eluted metal ions causes IM (ionic migration) to occur. Because of this, we were able to examine the process of diffusion and reduction of metal ions by causing changes in applied voltage and pH.

Fig. 8 shows the relationship between applied voltage and the occurrence of IM. One µL of ion-exchange water was dripped between the electrodes of a copper-clad glass epoxy PCB (conductor intervals, 0.318 mm) and the IM occurrence time was measured at each applied voltage level. The occurrence time was considered to be the time taken measuring from the application of voltage until IM reached the opposite electrode and short circuited.

This experiment confirmed that IM occurred at a minimum of 2 V DC, and occurrence was also reported at lower voltage.

Fig. 9 shows the relationship between pH and IM occurrence. One µL of pH 4 solution (phthalate solution), and pH 9.22 solution (borate solution), and ion-exchange water (measured pH = 6.6) was dripped

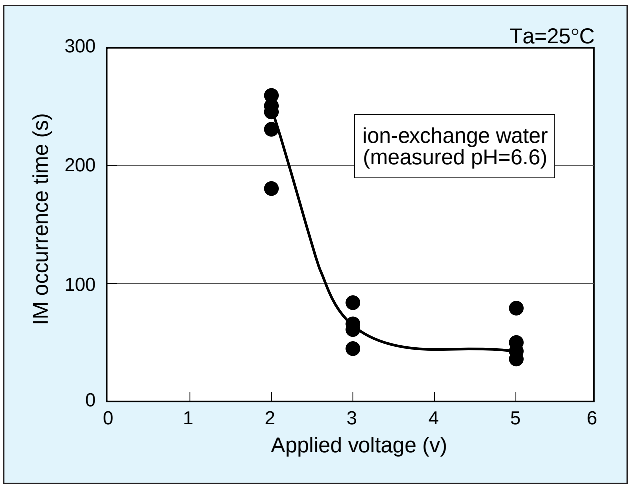


Fig. 8 The relationship between applied voltage and IM occurrence

onto the electrodes of copper-clad glass cloth epoxy PCBs (conductor intervals, 0.318 mm), and the IM occurrence time was measured at each applied voltage level.

The IM occurrence time was shorter for the pH 4 solution than for the ion-exchange water. However, IM occurred at 2 V DC in the ion-exchange water (Fig. 9), while IM did not occur in the pH 4 solution at that applied voltage. Since IM occurred in the ion-exchange water, we hypothesized that the phthalates in the pH 4 solution prevented the diffusion of the copper ions.

Bluish-white matter was observed to form on the anodes in the pH 9.22 solution. This result was considered to have been caused by copper hydroxide reduction forming on the anodes due to the diffusion time required, as copper ion elution accelerated slowly in the alkaline solution.[8)]

Applied voltage and pH are thought to greatly influence the occurrence of IM on PCBs during environmental tests.

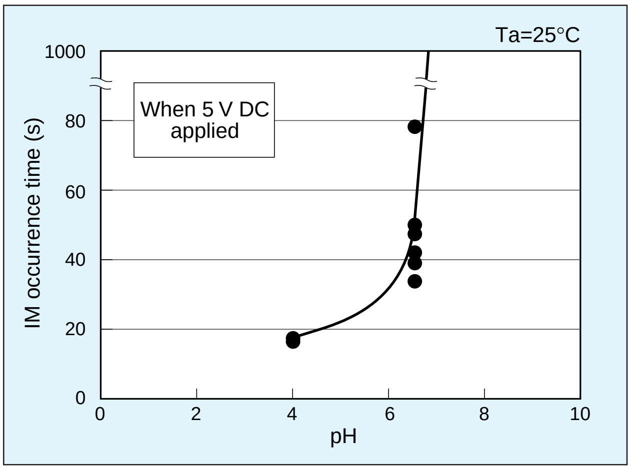


Fig. 9 The relationship between pH and IM occurrence

4. Conclusion

The insulation resistance characteristics seen during environmental testing are related to the absorption characteristics of the board and the electrical current characteristics. The absorption characteristics are determined by the PCB materials and environmental conditions, and the electrical current characteristics are affected by the elution of metal ions due to the electrolysis of water.

On the other hand, IM occurrence is caused by the process involving metal ion elution, diffusion, and reduction, which is affected by such factors as pH and applied voltage. Fig. 10 shows the mechanism of copper ionic migration.

Fig. 11 shows the relationship between the occurrence of IM and changes in insulation resistance during environmental testing. Changes in the insulation resistance values is considered to stem from the following three processes: ① The process of rising resistance values (Fig. 10, reactions 1 and 2, the elution of metal ions due to the adsorption and electrolysis of water); ② the process of stabilizing resistance values (Fig. 10, reaction 3, the elution and diffusion of metal ions): and, ③ the process of dropping resistance values and short circuiting (Fig. 10, reaction 4, metal ion reduction).

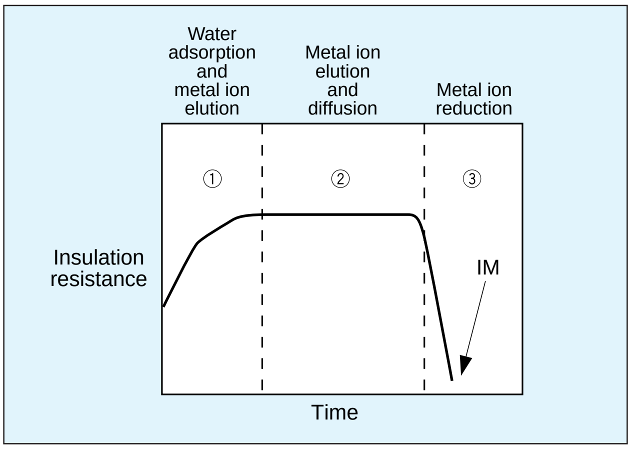


Fig. 11 The relationship between IM and insulation resistance characteristics (type diagram)

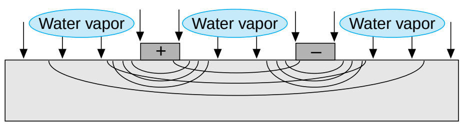
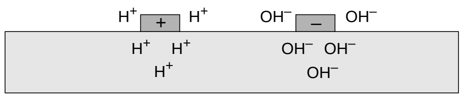
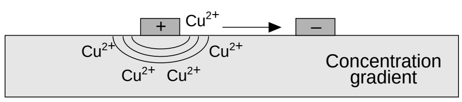
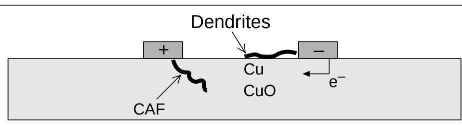
Reaction	Mechanism diagram	Acceleration factors
1. Water adsorption and diffusion		• Amount of water vapor (water amount) • Temperature • Material quality
2. Changes in pH due to the electrolysis of water (acidization)		• Voltage • Amount of water vapor (water amount) • Temperature
3. Copper elution and copper ion diffusion (diffusion)		• Voltage • Amount of water vapor (water amount) • Material quality • pH, impurity ions • Amount of dissolved oxygen
4. Electron transfer and IM occurrence (reduction)		• Voltage • Material quality • pH, impurity ions

Fig. 10 Occurrence mechanism for copper ionic migration

5. *Future themes*

During actual environmental testing, a variety of accelerating factors occur, such as adsorbed water, impurities on the board, adherence of substances and particles from inside the specimens, and the formation of dew during testing. Because of this, these factors must be considered and countermeasures must be studied when evaluating PCB insulation reliability.

Next time we would like to continue investigating IM occurrence mechanisms, and we also intend to consider some countermeasure methods.

Terms

*** 1 Adsorption**

Molecules of a gas or steam remaining on the surface of a solid or a liquid.

*** 2 Absorption**

Molecules of a gas or steam being taken inside a solid or a liquid.

*** 3 Electric double layer**

A very large electric potential gradient exists in the area extremely close to the surface of an electrode, and this is known to increase the likelihood of an electron transfer reaction. This area is called the electric double layer, and is several angstroms thick.

*** 4 Test stick for semiquantitative determination of copper**

Test paper used for qualitative analysis with a certain level of quantitative analysis added. The paper uses a color scale for comparing the changes in the color of the paper to indicate ion concentration.

*** 5 vs.SHE**

This is a method of showing the electrical potential gap by comparison to the potential of the Standard Hydrogen Electrode (SHE).

[Bibliography]

1) ANSI-J-STD-004, Requirements for Soldering Fluxes, 1997
2) Japaneses Standards Association, JIS-C-0033, Environmental testing. Part 2: Tests-Guidance for damp heat tests, 1993
3) The Electrochemical Society of Japan, “New Electrochemistry”, p.81-90, Baifukan
4) Tadashi Watanabe, Seiichi Nakabayashi, “The Chemistry of Electron Transfer”, Asakura Shoten, p.6-7, p.162-166
5) H.H.Uhlig, R.W.Revie, “Corrosion and Corrosion Control”, Sangyo Tosho, p.334-338
6) Tsutomu Tsukui, et al: “Ionic migration in circuit boards, and methods for its evaluation”, The Japan Institute of Printed Circuit, Insulation reliability research section, First conference report anthology, p.20-29
7) Kaichi Tsuruta, “Investigation of Migration on Printed Circuit Boards”, The Surface Finishing, vol.48, p.84-89
8) Yoshiyuki Tsuru, et al: “An investigation of copper migration”, The Japan Institute of Printed Circuit, Insulation reliability research section, First conference report anthology, p.14-19

Report 2

Psychrometer construction for performance testing in temperature and humidity chambers, and the precision of humidity measurements
—Meeting the challenge of quality engineering—

Hirokazu Nakahama*

When measuring the performance of the temperature and humidity chamber, industrial standards have adopted the psychrometer (performance testing psychrometer) as the standard humidity sensor. However, the standards do not discuss the construction of the psychrometer itself, prescribing only the psychrometer equation and the psychrometer coefficient to be used. Due to the improvement of humidity measurement technology and the development of traceability systems in recent years, we have again taken up the challenge of verifying psychrometer construction and humidity measurement precision.

This report will also introduce quality engineering methods that we have applied experimentally, as well as the methods we have used.

1. Introduction

The Japan Testing Machinery Association has established standards (hereafter, JTM standards) for methods of indicating performance of temperature and humidity chambers. These standards are known as JTM K 01:1998 “Humidity chambers-Test and indication method for performance”. These standards prescribe only the psychrometer (described in detail in section 3-1) as a humidity sensor for finding the humidity fluctuation and the humidity uniformity in the chambers. However, the standards say nothing at all about the details of the construction of the psychrometer used. Only the wind speed and the psychrometer equation to be used are stipulated. In this report, the psychrometer used to measure the humidity performance of a chamber will be called a psychrometer for performance tests, or merely a psychrometer.

The construction of the psychrometer for performance tests used at Tabai Espec is illustrated in the article “Humidity measurement and psychrometers in environmental testing equipment”, in Espec Technology Report No. 7. That illustration is reproduced here as Fig. 1.

A plastic container (such as an empty 35 mm film canister) is used as a water pot, the thermocouple (type T) is covered by a wick, and the device detects the wet-bulb temperature. We consulted the BS standards[1), 2)] concerning this construction, and we found that this psychrometer obtains a roughly valid reproducibility. However, the use of cooled mirror dew-point meters (hereafter, dew-point meters) has led to the development of quite accurate humidity traceability systems for humidity measurements both internationally and domestically. These developments make it necessary once again to accurately confirm the humidity measurement precision of psychrometers for performance tests.

For this report, we have used quality engineering methods to run experiments probing the construction psychrometers for performance tests and humidity measurement precision. This report also includes an introduction to quality engineering, providing a detailed look at the subject.

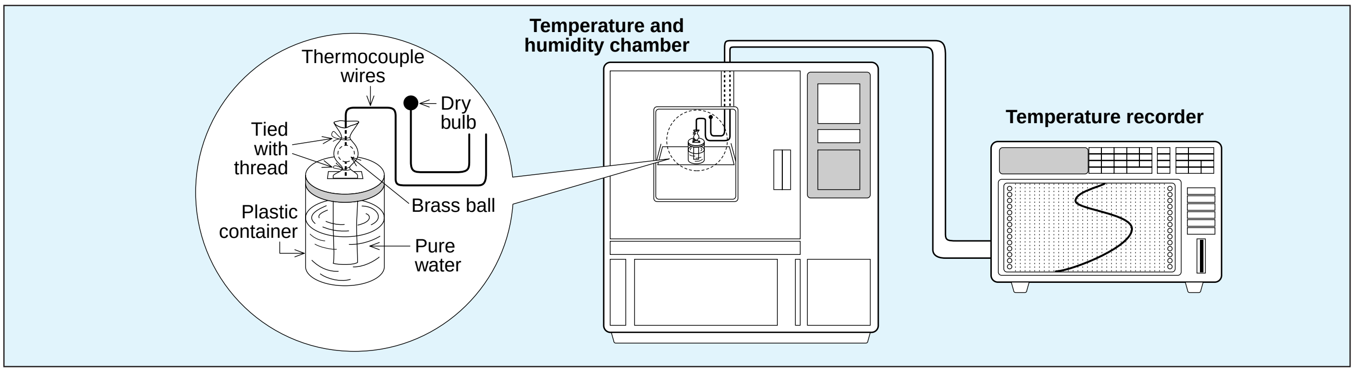


Fig. 1 Measuring temperature and humidity to evaluate equipment performance

*Technical Center

2. Quality engineering approach

2-1 Environmental testing and quality engineering

A quick way of learning something about quality engineering would be to do a keyword search on the internet for keywords such as “quality engineering” or “Taguchi methods”. Quality engineering is an evaluation method to determine the worth of specific technology. Doctor Genichi Taguchi advocated these methods, which are known as the “Taguchi methods” in the US.

The environmental testing equipment produced by Tabai Espec is widely used for testing production reliability. By exposing products to harsh environments in respect to such factors as temperature, humidity, pressure, and vibration, manufacturers can confirm whether products will operate normally in each environment, and are also able to estimate the life of the product.

When defects appear during final reliability testing of parts and products, making design changes as countermeasures at that time lengthens the development time frame. Should other defects appear as a result of the countermeasures, one can easily fall into an endless loop of design → prototype → performance confirmation. Furthermore, there are severe time constraints in testing long-term reliability. To speed development and obtain evaluation results quickly, composite environmental tests are used that combine all types of conditions. These are even harsher environmental tests such as the Highly Accelerated Stress Test (HAST) and the thermal shock test.

On the other hand, the quality engineering approach recommends using test pieces in environmental testing at the technical development stage. Test pieces are used to find design conditions, and so have less dispersion in characteristics, showing no change between characteristics in standard conditions and all types of environmental conditions and after test degradation. At this time, these are not the final product quality characteristics that will be listed in the catalog, but merely one index for evaluating the Signal-to-Noise Ratio (SN Ratio). This type of design method is called parameter design. Design conditions incorporating a high SN ratio have good reproducibility when manufactured as products, having a lower tendency to exhibit defects in the field. First of all, the design characteristics must have low dispersion, and then the characteristics must meet the required target values. This type of design method is called a two-stage design method.

2-2 SN ratio and ideal functions

The SN ratio compares the amount of signal to the amount of noise. With measuring instruments, changes in the object of measurement (input signal) as far as possible are output as linear reactions. Designs that are unaffected by all types of noise factors (noise) are said to have a high SN ratio and exhibit good performance. At present, there are no measuring instruments that are completely unaffected by noise, and so this remains an ideal, and is called ideal function.

With the psychrometer, the relationship between input and output as a measuring instrument can be conceptualized as shown in Fig. 2. This input/output relationship attains ideal form, and so consists of ideal function.

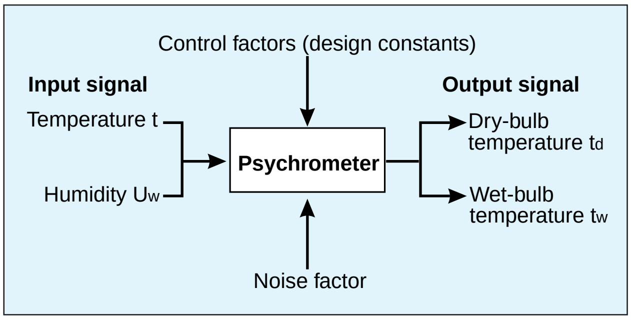


Fig. 2 Relationship between input and output in the psychrometer

Ambient temperature t and humidity U_w are the signal for the psychrometer. (This type of factor that serves as the input signal is called the “signal factor”.) Wet- and dry-bulb temperatures t_d and t_w are proportional to changes in the input signal, and can be output as characteristics values of the psychrometer. In other words, these can be indicated as follows.

$$t_d = t \quad (1)$$

$$t_w = f\,(t, U_w) \quad (2)$$

Design constants that can be set by the designer are called control factors. For example, wind speed can be set in the design, and so is a control factor for chamber control psychrometers. However, wind speed becomes a noise factor for psychrometers for performance tests, as it changes depending on the surrounding conditions. Wind speed that is measured and revised, though, is no longer a noise factor. Whether it is an noise factor or a control factor depends on the purpose of the experiment.

3. Setting experiment conditions

3-1 Psychrometer basics

The psychrometer is an instrument that uses two thermometers to simultaneously measure air temperature and humidity.

One thermometer is covered with a cloth called a wick, and is kept moist with water. This thermometer is called the wet-bulb thermometer in this report. The other thermometer is called the dry-bulb thermometer, and it measures ambient atmospheric temperature. In environmental testing equipment, the sensor probe of the dry-bulb thermometer is called the dry-bulb temperature sensor, and the sensor probe of the wet-bulb thermometer is called the wet-bulb temperature sensor.

When the ambient atmosphere is dry, moisture evaporates from the wick of the psychrometer, and so the temperature of the wet-bulb temperature sensor drops and reaches a certain equilibrium temperature. This temperature is called the wet-bulb temperature. The temperature of the ambient atmosphere at that time is called the dry-bulb temperature.

The basics of the input/output relationship of the psychrometer are expressed in the following formula.

$$t_d - t_w \infty e_{sw} - e \quad (3)$$

Where: t_d represents the dry-bulb temperature, t_w represents the wet-bulb temperature, e_{sw} represents the saturation water vapor pressure, and
e represents the partial pressure of water vapor in air.

The relationship found by Formula (3) is the psychrometer equation, and the coefficient for that equation is called the psychrometer coefficient. The most commonly used of the psychrometer formulas is the following Sprung formula.[3)]

$$e = e_{sw} - A \cdot p\,(t_d - t_w) \quad (4)$$

Where: p represents atmospheric pressure, A represents the psychrometer coefficient, and A = 0.000662 (K^{-1}) when the wet-bulb is not frozen.

The wind speed must be at least 2.5 m/s (there is some variation in the literature). Any pressure units can be used as long as they are unified, but the unit currently used is the Pascal (Pa).

Using the wet-bulb temperature and the dry-bulb temperature, the water vapor partial pressure in the atmosphere is found according to the psychrometer equation, and the relative humidity is calculated. Relative humidity U_w (%RH) is defined by the following formula.

$$U_w = (e/e_s) \times 100 \quad (5)$$

Where e_s represents the saturation water vapor pressure at dry-bulb temperature.

In the JTM standards, when a minimum 2.5 m/s wind speed cannot be maintained, the following Pernter formula is used. Table 1 shows the coefficients for that formula.

$$e = e_{sw} - a \cdot p\,(t_d - t_w)\,(1 + t_w/b) \quad (6)$$

Table 1 Coefficients for the Pernter formula

Wet-bulb vicinity wind speed (m/s)	When the wet-bulb is not frozen	
	a	b
Calm 0 to 0.5	0.0012	610
Weak breeze 1.0 to 1.5	0.0008	610
Strong breeze Min. 2.5	0.000656	610

3-2 Signal factor

The input signal for the psychrometer consists of the ambient temperature and humidity for the psychrometer. The psychrometer equation can be thought of as a calibration formula for humidity, and so here instead of scrutinizing that equation, we will use the Sprung formula.

The temperature and humidity measured on a standard thermometer and hygrometer is taken as the standard temperature and humidity that should naturally be shown on a psychrometer. First of all, the atmospheric temperature as measured on a standard thermometer is set as standard dry-bulb temperature T_d. Next, the standard wet-bulb temperature T_w that should be shown on the psychrometer is calculated from aforementioned standard dry-bulb temperature T_d and dew-point D_p measured on a standard hygrometer with the dew-point calibrated. Then, the standard wet- and dry-bulb temperature differential ($T_d - T_w$) is found. The same ambience is simultaneously measured with psychrometers of various types of construction, and the wet- and dry-bulb temperature differential ($t_d - t_w$) is found. The optimum psychrometers for performance tests will have little dispersion of ($t_d - t_w$) relative to ($T_d - T_w$), having good straight-line characteristics even in the presence of all types of noise. A psychrometer with a systematic deviation can be corrected afterwards.

Fig. 3 shows this relationship as a zero-point proportional formula.

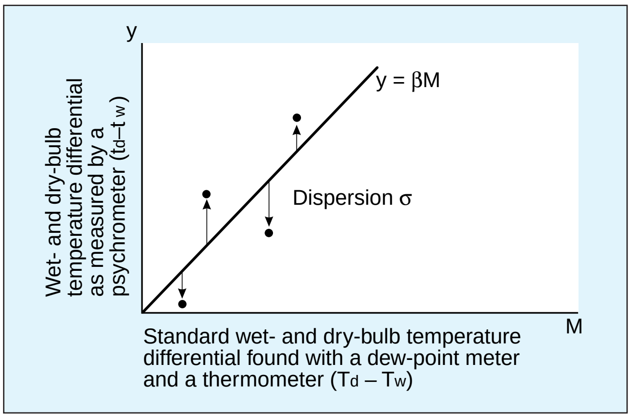


Fig. 3 The relationship between signal factor M and output y

Quality engineering takes the input signal M on the horizontal axis and the output signal y on the vertical axis and displays the signal as the proportional coefficient β.

The signal factors are the 4 temperature and humidity conditions shown in Table 2. These four conditions are taken as the temperature and humidity settings for the chamber, and the amount (the calculated value) of moisture in the air at that time is shown on the instruments. Performance limitations of the dew-point meter make it difficult to measure the dew-point in high-temperature, high-humidity regions, and so the upper bound was set at 85°C and 90 %rh.

Table 2 Signal factors and conditions (calculated values)

Temperature and humidity settings		Air moisture levels		
Dry-bulb temperature	Relative humidity	Dew-point	Wet-bulb temperature	Wet- and dry-bulb temperature differential
t_d (°C)	U_w (%rh)	D_p (°C)	T_w (°C)	$T_d - T_w$ (°C)
10	50	0.1	5.6	4.4
	90	8.4	9.2	0.8
85	20	48.7	52.2	32.8
	90	82.3	82.4	2.6

3-3 Control factors

Fig. 4 shows the wet-bulb construction of psychrometers for performance tests. Seven control factors were taken up. These are shown in Table 3. As Table 5 shows, the control factors were apportioned as in the inside orthogonal array L_{18}.

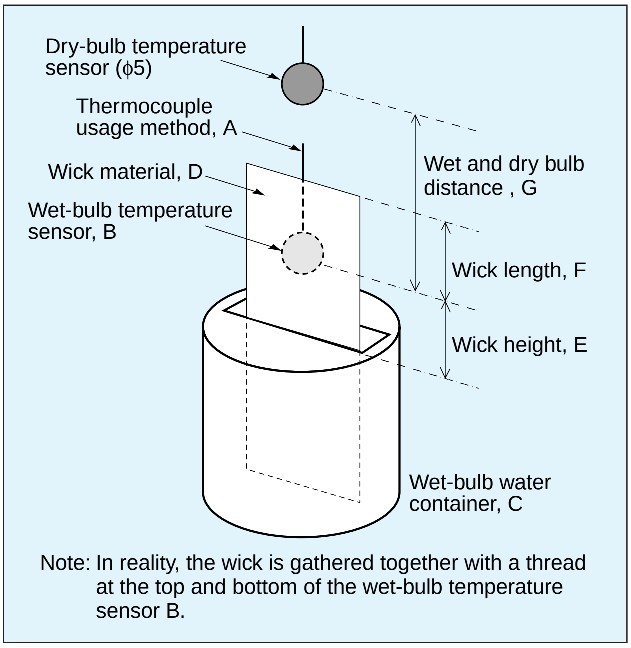


Fig. 4 Design and control factors for psychrometers for performance tests

Table 3 Control factors and their levels

Symbols	Control factors	Levels		
A	Thermocouple usage method	A1: Usual formula	A2: Differential method	—
B	Wet-bulb temperature sensor	B1: Bare wire only	B2: ϕ3 mm brass ball attached	B3: ϕ5 mm brass ball attached
C	Wet-bulb water container	C1: Lactic acid bacterium beverage container	C2: 35 mm film canister	C3: Sample bottle*
D	Wick material	D1: Non-woven nylon fabric	D2: Bleached cotton	D3: Gauze
E	Wick height	E1: 10 mm	E2: 20 mm	E3: 30 mm
F	Wick length	F1: 10 mm	F2: 30 mm	F3: 50 mm
G	Wet and dry bulb distance	G1: Wet- and dry-bulb coordinated positions	G2: Dry-bulb 25 mm upwind	G3: Dry-bulb 50 mm upwind

* Plastic cylindrical container, diameter 30 mm, height 50 mm

3-4 Noise factors and signal factors

We have taken up the following 3 items as noise factors: wind speed, wind direction, and sampling position of the dew-point meter. These are shown in Table 4.

Table 4 Noise factors and their standards

Symbols	Noise factor	Levels	
H	Wind speed (m/s)	H1: 1.0 to 1.5	H2: ≧ 2.5
I	Wind direction	I1: Straight up	I2: Facing
J	Sampling position of dew-point meter	J1: Fixed	J2: Equidistant

Temperature and humidity (refer to Table 2) are combined as signal factors, and were apportioned as in the outside orthogonal array L_8 in Table 5.

These experiments use complex noise factor combinations, which required longer times for running the experiments. The aim was narrowed down to the crucial noise factor of wind speed, and this was thought to have satisfactorily speeded up the experiments.

3-5 Experiment combinations

Table 5 shows the experiment combinations. In other words, the 18 different types of psychrometer construction were each measured with 8 sets of conditions, resulting in the experiment being run 144 times (18 × 8).

Table 5 Assignment of experiment factors

Outside orthogonal array L_8

Row	Factor	No. 1	2	3	4	5	6	7	8
1	**Temperature**	10°C	10°C	10°C	10°C	85°C	85°C	85°C	85°C
2	**Humidity**	50%rh	50%rh	90%rh	90%rh	20%rh	20%rh	90%rh	90%rh
3	—	—	—	—	—	—	—	—	—
4	**Wind speed**	1.0 to 1.5	≧ 2.5	1.0 to 1.5	≧ 2.5	1.0 to 1.5	≧ 2.5	1.0 to 1.5	≧ 2.5
5	**Wind direction**	Straight up	Facing	Straight up	Facing	Facing	Straight up	Facing	Straight up
6	**Sampling position**	Fixed	Equidistant	Equidistant	Fixed	Fixed	Equidistant	Equidistant	Fixed
7	—	—	—	—	—	—	—	—	—

Inside orthogonal array L_{18}

Row	1	2	3	4	5	6	7	8	No. 1	2	3	4	5	6	7	8
Control factors	**Thermocouple usage method**	**Wet-bulb sensor**	**Wet-bulb water container**	**Wick material**	**Wick height**	**Wick length**	**Wet and dry bulb distance**	**Experient margin of error**								
Symbols	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**e**								
Experiment No.1	Common method	Bare wire only	Lactic acid bacterium beverage container	Non-woven nylon fabric	10mm	10mm	0mm	1	y11	y12	y13	y14	y15	y16	y17	y18
2	Common method	Bare wire only	35 mm film canister	Bleached cotton	20mm	30mm	25mm	2	y21	...	...	...	...	...	...	y28
3	Common method	Bare wire only	Sampling bottle	Gauze	30mm	50mm	50mm	3	y31	...					...	y38
4	Common method	ϕ3 brass ball	Lactic acid bacterium beverage container	Non-woven nylon fabric	20mm	30mm	50mm	3	y41	...					...	y48
5	Common method	ϕ3 brass ball	35 mm film canister	Bleached cotton	30mm	50mm	0mm	1	y51	...					...	y58
6	Common method	ϕ3 brass ball	Sampling bottle	Gauze	10mm	10mm	25mm	2	y61	...					...	y68
7	Common method	ϕ5 brass ball	Lactic acid bacterium beverage container	Bleached cotton	10mm	50mm	25mm	3	y71	...					...	y78
8	Common method	ϕ5 brass ball	35 mm film canister	Gauze	20mm	10mm	50mm	1	y81	...					...	y88
9	Common method	ϕ5 brass ball	Sampling bottle	Non-woven nylon fabric	30mm	30mm	0mm	2	y91	...		yij			...	y98
10	Differential method	Bare wire only	Lactic acid bacterium beverage container	Gauze	30mm	30mm	25mm	1	y101	...					...	y108
11	Differential method	Bare wire only	35 mm film canister	Non-woven nylon fabric	10mm	50mm	50mm	2	y111	...					...	y118
12	Differential method	Bare wire only	Sampling bottle	Bleached cotton	20mm	10mm	0mm	3	y121	...					...	y128
13	Differential method	ϕ3 brass ball	Lactic acid bacterium beverage container	Bleached cotton	30mm	10mm	50mm	2	y131	...					...	y138
14	Differential method	ϕ3 brass ball	35 mm film canister	Gauze	10mm	30mm	0mm	3	y141	...					...	y148
15	Differential method	ϕ3 brass ball	Sampling bottle	Non-woven nylon fabric	20mm	50mm	25mm		y151	...					...	y158
16	Differential method	ϕ5 brass ball	Lactic acid bacterium beverage container	Gauze	20mm	50mm	0mm	2	y161	...					...	y168
17	Differential method	ϕ5 brass ball	35 mm film canister	Non-woven nylon fabric	30mm	10mm	25mm	3	y171	...	...	...	...	...	...	y178
18	Differential method	ϕ5 brass ball	35 mm film canister	Bleached cotton	10mm	30mm	50mm	1	y181	y182	y183	y184	y185	y186	y187	y188

3-6 Experiment equipment

Fig. 5 shows an outline of the equipment used in these experiments. An air duct (arc-shaped) is installed inside the chamber with controlled temperature and humidity settings, and the type of psychrometer corresponding to each experiment number is installed inside the air duct. A standard thermometer and dew-point meter are also installed to simultaneously measure the temperature and humidity inside the air duct.

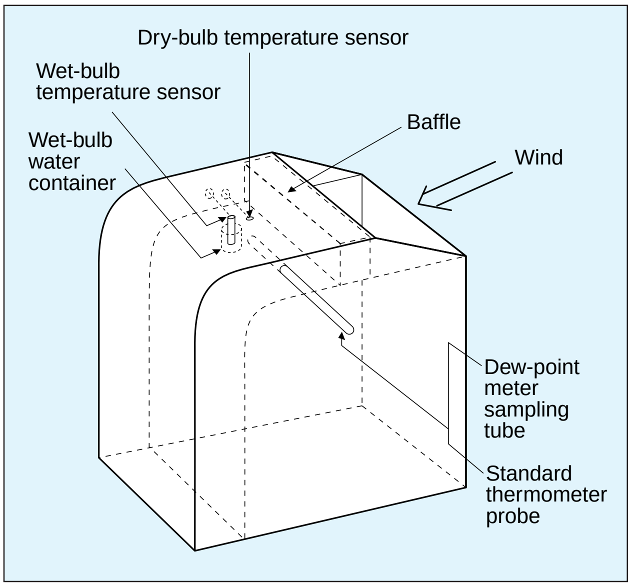


Fig. 5 Outline of experiment equipment

3-7 Experiment results

3-7-1 Measured temperature and humidity versus standard temperature and humidity

Table 6 shows a portion of the measurement data collected using psychrometers for performance tests along with standard thermometers and dew-point meters. The data in Table 6 was collected using the inside orthogonal array No.1 psychrometer and measured using the conditions in outside orthogonal array No.2, both shown in Table 5.

Table 6 Measurement data examples: Experiments No. 1-2

Time	Standards inside the air duct		Psychrometers for performance tests	
	Dry-bulb temperature	Dew-point	Dry-bulb temperature	Wet-bulb temperature
(min)	T_d (°C)	D_p (°C)	T_d (°C)	T_w (°C)
0	9.8	–0.62	9.6	5.7
1	9.7	–0.07	9.5	5.6
...	...	...	...	...
11	9.7	–0.57	9.6	5.8

The air duct is placed inside the chamber, and after the temperature and humidity are stabilized inside the air duct, 11 measurements are taken at intervals of one minute each, and this data is used to calculate the SN ratio.

3-7-2 Calculating the SN ratio

For each of the experiments No.1 through 18 in orthogonal array L_{18}, the input signal is defined as the standard wet- and dry-bulb temperature differential ($T_d - T_w$), and the output signal is defined as the wet- and dry-bulb temperature differential ($t_d - t_w$) as measured on the psychrometer. The SN ratio is found using the zero-point proportional formula. Let's look now at the calculation sequence used to find the SN ratio in experiment No.1.

Total fluctuation S_T

S_T = the sum of squares of the individual data

$$= y_{111}^2 + \ldots + t_{1111}^2 + y_{121}^2 + \ldots + y_{1211}^2 + \ldots + y_{181}^2 + \ldots + y_{1811}^2$$

Where y_{ijk} is the wet- and dry-bulb temperature differential ($t_d - t_w$) of the psychrometer for performance tests. In other words, i represents the 18 types of psychrometers, j represents which of the 8 times the experiment was performed with each psychrometer, and k represents the measurement repetition number (1 to 11) in each experiment. In experiment No.1, i = 1, j = 1 to 8, and k = 1 to 11.

Primary fluctuation S_β

$$S_\beta = (y_{111}\cdot M_{111} + y_{112}\cdot M_{112} + \ldots + y_{1111}\cdot M_{1111} + y_{121}\cdot M_{21} + y_{122}\cdot M_{122} + \ldots + y_{1211}\cdot M_{1211} + \ldots + y_{181}\cdot M_{181} + y_{182}\cdot M_{182} + \ldots + y_{1811}\cdot M_{1811})^2/r$$

Where M_{ijk} is the standard wet- and dry-bulb temperature differential ($T_d - T_w$), and is calculated from dew-point D_p measured with a dew-point meter and the dry-bulb temperature T_d measured with a standard thermometer. Temperature and humidity settings include 4 sets of conditions, but the number of experiments is j = 8.

Effective divisor r

$$r = M_{111}^2 + \ldots + M_{1111}^2 + M_{121}^2 + \ldots + M_{1211}^2 + \ldots + M_{181}^2 + \ldots + M_{1811}^2$$

Error fluctuation S

$$S_e = S_T - S_\beta$$

Error variance V_e

$$V_e = S_e/f_e$$

Where f_e is the degree of freedom, and since there are 88 individual bits of data, f_e here is 87.

Sensitivity β^2

$$\beta^2 = (S_\beta - V_e)/r$$

Dispersion σ^2

$$\sigma^2 = V_e$$

SN ratio η

$$\eta = \beta^2/\sigma^2 = (S_\beta - V_e)/(r\cdot V_e)$$

Normally, SN ratio η is expressed in decibel (db) units as in the following.

$$\text{SN ratio } \eta \text{ [db]} = 10\text{Log } \eta = 10\text{Log}\{(S_\beta - V_e)/(r\cdot V_e)\}$$

The above calculation was repeated for each of the 18 types of psychrometer construction.

Displaying the SN ratio in decibels is done to express the additiveness of the factorial effect. For detailed meanings, refer to the drawings.[5)]

3-7-3 SN ratio effects

Table 7 shows the SN ratio for each experiment number. Table 8 shows the SN ratio calculated from Table 7 for each factor level. The SN ratio is averaged for the 18 psychrometer types which include the factor levels found.

Table 7 SN ratio

Experiment No.	SN (db) η
No. 1	7.379
No. 2	2.608
No. 3	9.725
No. 4	15.699
No. 5	6.727
No. 6	7.238
No. 7	14.040
No. 8	6.299
No. 9	13.948
No. 10	3.861
No. 11	11.757
No. 12	–2.410
No. 13	0.343
No. 14	5.895
No. 15	10.120
No. 16	10.131
No. 17	9.683
No. 18	10.795
Average	7.991

Table 8 SN ratio for each factor level

Sym-bols	Control factors	Level symbols	Level details	Total SN ratio for each level	SN ratio (db) for each level
A	Thermocouple usage method	A1	Common method	83.663	9.296
		A2	Differential method	60.173	6.686
B	Wet-bulb temperature sensor	B1	Bare wire only	32.919	5.487
		B2	ϕ3 mm brass ball	46.022	7.670
		B3	ϕ3 mm brass ball	64.896	10.816
C	Wet-bulb water container	C1	Lactic acid bacterium beverage container	51.453	8.576
		C2	35 mm film canister	42.969	7.161
		C3	Sample bottle	49.415	8.236
D	Wick material	D1	Non-woven nylon fabric	68.586	11.431
		D2	Bleached cotton	32.102	5.350
		D3	Gauze	43.149	7.191
E	Wick height	E1	10mm	57.104	9.517
		E2	20mm	42.446	7.074
		E3	30mm	44.287	7.381
F	Wick length	F1	10mm	28.531	4.755
		F2	30mm	52.806	8.801
		F3	50mm	62.499	10.416
G	Wet and dry bulb distance	G1	Wet- and dry-bulbs in same position	41.670	6.945
		G2	Dry-bulb 25 mm upwind	47.549	7.925
		G3	Dry-bulb 50 mm upwind	54.617	9.103
				Average	7.991

Fig. 6 shows the SN ratio for each control factor level.

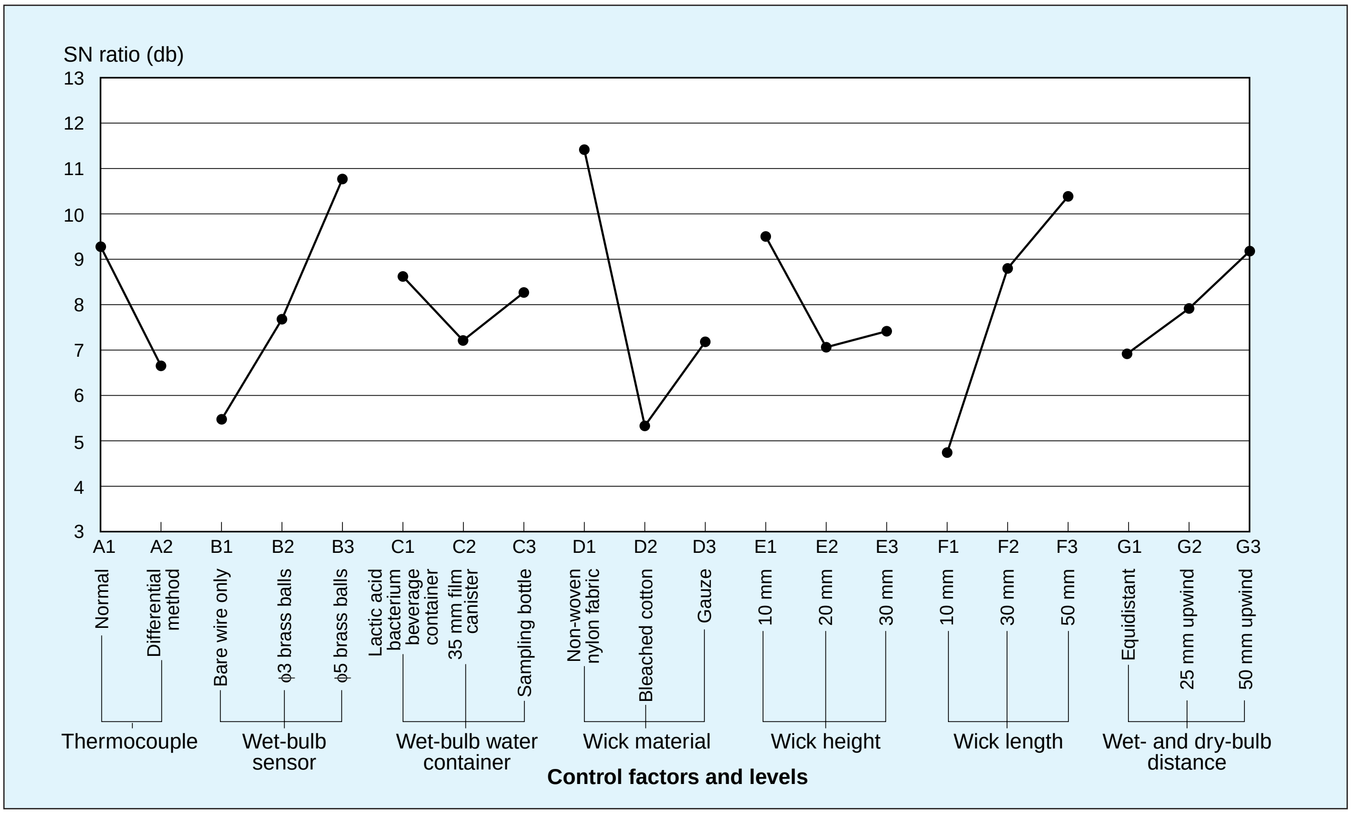


Fig. 6 SN ratios for each control factor and level

3-7-4 Analysis of variance for SN ratios

Table 9 shows analyses of variance for SN ratios. When factors with relatively small variance are pooled (here, C, E, and G), the results become as shown in Table 10. The factorial effect of A, B, C, and D is large.

Table 9 Analysis of variance for SN ratios

Factor	Degree of freedom f	Fluctuation S	Variance V
A: Thermocouple	1	30.6545	30.6545
B: Wet-bulb sensor	2	86.1346	43.0673
C: Wet-bulb water container	2	6.5382	3.2691
D: Wick material	2	116.6722	58.3361
E: Wick height	2	21.2519	10.6259
F: Wick length	2	102.0557	51.0278
G: Wet- and dry-bulb distance	2	14.0080	7.0040
Error e	4	13.7100	3.4275
Total	17	391.0251	

Table 10 Variance analysis table after pooling

Factor	Degree of freedom f	Fluctuation S	Variance V	Variance ratio *Fo*	Contribution ratio *p* (%)
A: Thermocouple	1	30.6545	30.6545	5.52	6.4
B: Wet-bulb sensor	2	86.1346	43.0673	7.76	19.2
D: Wick material	2	116.6722	58.3361	10.51	27.0
F: Wick length	2	102.0557	51.0278	9.19	23.3
Error e	10	55.5081	5.5508		24.1
Total	17	391.0251			100

3-8 Confirmation experiments

3-8-1 Confirming the SN ratio

The size of the SN ratio was considered along with other factors, and confirmation experiments were run with current conditions and with combinations of the best and worst conditions as shown in Table 11. The current conditions used in these experiments refers to the psychrometer for performance tests seen in Fig.1, used by Tabai Espec.

Table 11 shows the SN ratios estimated from the results in section 3-7, compared to the SN ratio measured in confirmation experiments with these conditions.

The reasons for the combinations of factors and levels are as follows.

A precision digital voltmeter is deemed suitable for use with a level A2 differential thermocouple. However, a differential thermocouple is not generally used for measuring temperature. Therefore, A1 was done in the same way. The lactic acid bacterium beverage container in level C1 does not have good heat resistance and deforms at 85°C, and so it was excluded. Wick height E and wick length F are often limited by the total length of the wick, and so the combinations given above were set.

Table 11 Control factor combinations and estimated vs. measured SN ratios

Control factor combinations	Estimated value		Measured value	
	SN ratio	Gain	SN ratio	Gain
1. Current conditions: A1B3C2D1E1F1G2	12.3	—	17.7	—
2. Best conditions: A1B3C3D1E1F3G3	18.0	5.7	17.8	0.1
3. Worst conditions: A1B1C2D2E1F1G2	0.9	–11.4	–7.1	–24.8

The average value of SN ratio $\overline{T}$ in Table 8 was set for the estimated value of the SN ratio, and was included in the SN ratio for each of the factors with a large factorial effect (A, B, D, and F) and the totals were calculated. The estimated values of the SN ratios with the current conditions were calculated in the following way.

Current conditions:

$A1 + B3 + D1 + F1 - 3 \times \overline{T}$

$= 9.296 + 10.816 + 11.431 + 4.755 - 3 \times 7.991$

$= 12.3$ (db)

Calculations for the best and worst conditions were done in the same way.

As you can see in Table 11, the SN ratio was high at the best conditions, but there was little difference in results at best conditions and current conditions. The results from the worst conditions were clearly bad. However, the SN ratios estimated from the orthogonal array experiments were not fully reproduced in the confirmation experiments. Further study is needed in the method of conducting the experiments in regard to such matters as whether to handle standard humidity as a signal factor. For signal M in Fig. 3, it would be possible to use the difference between standard wet-bulb temperature T_d and standard dew-point D_p ($T_d - D_p$), but that doesn't yield a linear proportional equation. It can also be considered as a difference in water vapor pressure. Also, it would probably be better to use a wider range for the wind speed as a noise factor, from a natural convection current to a strong wind.

The fundamental factors in humidity measurements with the psychrometer are thermal conduction and evaporation of water on the wet bulb. In B1, the thermocouple bare wire only serving as the wet-bulb sensor is thought to provide insufficient thermal conductivity with the wick. Also, with the non-woven nylon fabric in D1, the fiber has no unevenness and is thought to be more likely to provide even evaporation.

Wick length F requires a certain length to prevent thermal conductivity from the thermocouple wire to the wet bulb. The length should be from 30 to 50 mm, longer than the currently used conditions (F1 = 10).

For wet and dry bulb distance G, better results are obtained by placing the dry bulb upwind, but this doesn't really make much difference since the wind direction is not fixed inside the actual chamber.

3-8-2 Confirmations with relative humidity

Table 12 shows the deviation from standard relative humidity. The standard relative humidity is found by converting from values measured with a dew-point meter and a standard thermometer. To arrive at the deviation, these results are compared with the relative humidity (%rh) derived from the wet- and dry-bulb temperature t_w and t_d measured with the psychrometer.

The wind speed in the Sprung formula was handled as a noise factor, and the psychrometer coefficient A = 0.000662 (K^{-1}) was used for all cases. For reference, calculations were also made with the Pernter formula using a separate value for the psychrometer coefficient for each wind speed.

4. Conclusion

When calculating the psychrometer for performance tests with current conditions using the Pernter formula, and handling the wind speed as a noise factor, measured values shift higher in the low-temperature, low-humidity region with low wind speed. However, when the wind speed is measured and calculated with the Pernter formula even at low wind speeds accurate measurements can be made in all temperature and humidity regions.

When calculating the psychrometer for performance tests with best conditions using the Sprung formula, and handling wind speed as a noise factor, even with low wind speed accurate measurements can be made in all temperature and humidity regions. We were able to improve only slightly on the current conditions for the construction of the psychrometer.

When using psychrometers with unsuitable construction, error can exceed 10 %rh, and the standard deviation becomes rather large, reaching 1.0 %rh.

When using either current conditions or best conditions, the standard deviation shows little change and remains within 0.8 %rh. Even with current conditions, valid reproducibility was obtained, backing up the results.

These experiments handled wind speed as a noise factor, using the Sprung formula even with low wind speeds from 1 to 1.5 m/s. While the Pernter formula was

Table 12 Relative humidity deviation (%rh) from standard humidity

	Psychrometer construction											
	Current conditions				Best conditions				Worst conditions			
Experi-ment No.	Sprung formula		Pernter formula		Sprung formula		Pernter formula		Sprung formula		Pernter formula	
	m	σ_{n-1}	m	σ_{n-1}	m	σ_{n-1}	m	σ_{n-1}	m	σ_{n-1}	m	σ_{n-1}
1	6.6	0.55	2.1	0.59	2.7	0.56	–2.3	0.60	15.0	0.90	10.9	0.96
2	2.7	0.49	2.7	0.49	–0.6	0.71	–0.6	0.71	9.3	0.67	9.3	0.67
3	2.1	0.56	0.9	0.60	1.2	0.60	0.0	0.65	4.8	0.68	3.9	0.70
4	1.1	0.76	1.0	0.76	–0.7	0.68	–0.8	0.68	4.1	0.40	4.0	0.40
5	1.2	0.03	0.1	0.06	0.2	0.07	–1.0	0.07	5.8	0.06	4.8	0.06
6	1.4	0.07	1.2	0.07	0.3	0.06	0.0	0.06	5.4	0.09	5.2	0.09
7	0.4	0.25	0.2	0.25	–0.4	0.27	–0.5	0.27	0.7	0.40	0.5	0.40
8	0.7	0.19	0.6	0.19	0.2	0.18	0.2	0.18	0.7	0.19	0.6	0.19

Notes: m = average value, σ_{n-1} = standard deviation, n = 11

No.2, 4, 6, 8: Wind speed > 2.5 m/s, No.1,3,5,7: Wind speed = 1.0 to 1.5 m/s No.1,2: 10°C, 50% rh; No.3,4: 10°C, 90% rh; No.5,6: 85°C, 20% rh; No.7,8: 85°C, 90% rh able to provide the coefficients for each wind speed, the wind speeds were scattered over a wide range, and so the question arose as to how to handle that gap.

Realistically, the Sprung formula can be applied as is when the wind speed rises above 1.5 m/s. When the wind speed is in the range of 0.5 to 1.5 m/s, the Pernter formula weak wind coefficient can be used. However, the psychrometer construction, as shown in these experiments, needs to be optimized.

5. A final word

Follow-up experiments on performance evaluation humidity sensors for temperature and humidity chambers need to consider results using not only psychrometers, but also other types of hygrometers such as electronic humidity sensors. So-called humidity sensors have some reliability concerns due to changes over long periods of time and due to problems with environmental resistance, but these effects can be considered slight when the devices are used for short periods. In such cases, calibration becomes problematic, but calibration methods using quality engineering have become standardized even at JIS.

Recently, quality engineering has become widely applied in a number of fields as a method of reducing the development period and lowering costs for new products as well as reducing the number of customer complaints.

Within this trend, environmental testing is an extremely important factor. If the product functions do not suffer changes in a variety of environmental conditions, deterioration of functions should not be expected from the usage conditions in the field. We at Tabai Espec will continue to offer the best environmental testing methods available.

[Bibliography]
1) BS3898, “Specification for Laboratory humidity ovens (injection type)”, 1965
2) BS4864, “Recommendations on the design and testing of enclosures for environmental testing”, 1973
3) JIS Z 8806, “Humidity-measurment methods”, 1995
4) JTM K 01, “Humidity chambers—Test and indication method for performance”, 1998
5) Genichi Taguchi, “Taguchi Methods”, vol.1-7, Japanese Standards Association
6) JIS Z 9090, “Measurement-General rules for calibration system”, 1991

Topics

Applications of the Fast Cycle Chamber

Keiko Toi*　Hiroyuki Mishima*

1. Introduction

The market for cellular phones, mobile information equipment, and car electronics is continuing to show explosive growth. Competition is heating up as manufacturers invest major efforts in the research and development race for new parts and materials to create new products. The intensity of this competition has led to dramatic increases in such needs as improving reliability of devices and products, increasing mounting density, expanding the range of product application, utilizing new materials, improving safety, reducing development time, and lowering testing costs. To meet these needs, Tabai Espec has developed a new environmental test chamber called the Fast Cycle Chamber.

2. Appearance and specifications

Photo 1 shows the new unit, and Table 1 gives the main specifications.

Photo 1 Fast Cycle Chamber

Table 1 Main specifications

Item	Specification
Temperature range	–60°C to +150°C
Outer dimensions	W800 × H1115 × D1000 mm
Inner dimensions	W380 × H100 × D320 mm
Capacity	12 L
Temperature heat-up rate	From –40°C to +100°C, within 10 min (no load, refrigerator off)
Temperature pull-down rate	From +20°C to –40°C, within 10 min (no load)
Permissible heat load	Max.800W (at –40°C) *refrigerator control: HIGH setting
Instrumentation	Language:English, Program instrumentation (touch panel type)
Refrigerator	Hermetically sealed compressor
Refrigerant	Low temp. side:R508A (HFC), High temp. side:R404A (HFC)
Components	• Casters (with adjustor foot) • Cable clamp • Viewing window (on top)
Main options	• Temperature recorder • Communication function (RS-232C, GP-IB)

3. Features

Higher temperature change rate

This model achieves a much higher rate of temperature change than conventional temperature chambers. This makes it possible to reduce temperature conversion time, thus reducing total test time.

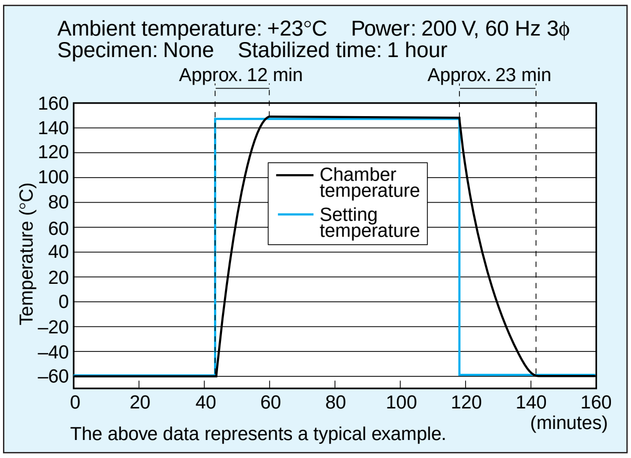


Fig. 1 Temperature characteristics from –60°C to +150°C

*R & D Center

Temperature change rate settings

The temperature change rate can be set by the user to the maximum change capacity.

HFC countermeasures to benefit the global environment

The refrigerant is HFC, which has a zero ozone layer depletion potential. This model meets the need to protect the ozone layer based on the regulations from the Meeting of the Parties to the Montreal Protocol on Substances.

Constant mode operation at indicated settings

The high-level insulation capacity not only offers temperature change testing, but also makes possible constant mode operation at both low and high temperature settings.

Test cost reduction

Reducing the temperature setting conversion time (temperature heat-up rate, and pull-down rate) makes it possible to consume less power than with a conventional temperature chamber, thus reducing the total cost of the test. (Fig. 2, Table 2)

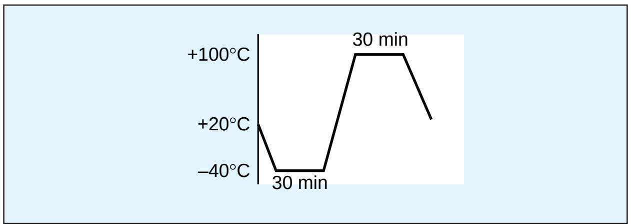


Fig. 2 Sample operation pattern A

Table 2 Comparison of power consumption and time requirements for sample operation pattern A

(measurement results)

Product	Power consumption (Wh)	Time required
Fast Cycle Chamber	3313.12	1 h, 16 min
Tabai Espec small temperature chamber	3556.74	2 h, 25 min
Tabai Espec temperature chamber	5889.64	2 h, 8 min

Viewing window

A viewing window is provided as standard equipment for observing specimens during the tests. (Photo 1)

Test area drawer

A test area drawer is provided for ease of placing specimens in the chamber. (Photo 1)

Cable clamp

The specimen can be placed inside the chamber with the wiring hooked up to devices such as power supplies and measuring equipment. (Photo 2)

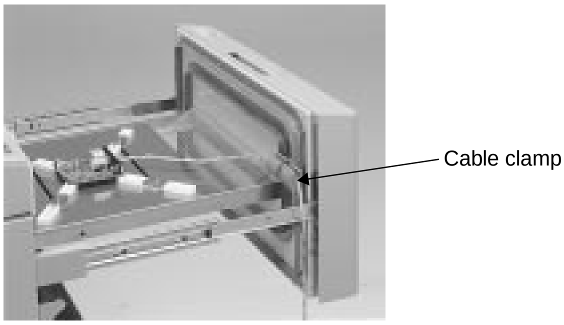


Photo 2 Cable clamp

4. *Testing with the Fast Cycle Chamber*

Below are examples of actual tests using the Fast Cycle Chamber.

4-1 Temperature characteristics test

Temperature change time can be reduced for temperature characteristics measurement, one of the characteristics measured for electronic parts. For example, in a case such as in Fig. 3, approximately 151 minutes can be saved in the total test time.

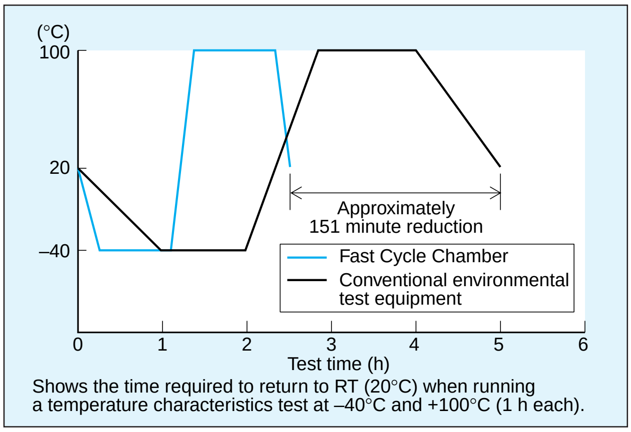


Fig. 3 Comparison of test times for Fast Cycle Chamber and conventional equipment

4-2 Temperature cycling test

Some thermal shock cycling test conditions can be too severe for some specimens, making a somewhat milder temperature change rate desirable. The Fast Cycle Chamber makes it possible for the user to set the rate of temperature change. These settings can be used to conform to temperature change rate requirements such as the export product testing requirements for North America (example of standards: US industrial standard IPC-SM-785 of the Institute of Interconnecting and Packaging Electronic Circuits).

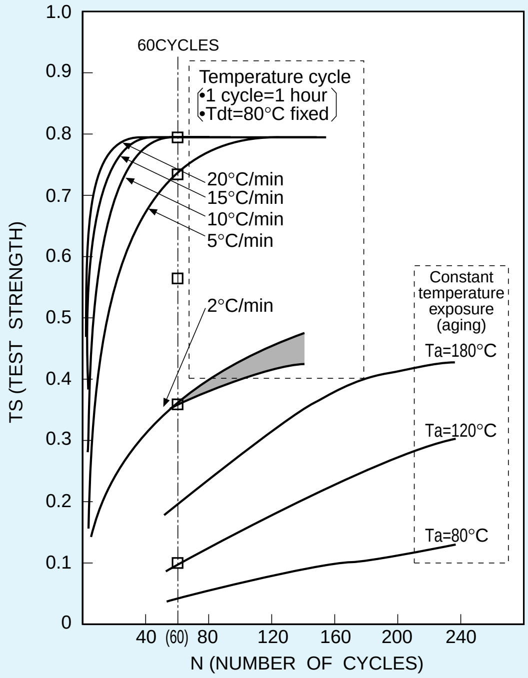
4-3 Environmental stress screening

Environmental stress screening (ESS) is widely used in places such as the US as a screening test. Using performance inspections within manufacturing processes, some product defects are considered detectable (actual defects) and some are undetectable (potential defects). Tests such as temperature cycling tests and random vibration tests are considered effective as methods of detecting the potential defects. As Fig. 4 shows, the temperature change rate in temperature cycling tests is reported to be from 5 to 15°C per minute, obtaining a rate of acceleration approximately 8 times faster than the constant temperature tests. The Fast Cycle Chamber is able to attain this temperature change rate of from 5 to 15°C per minute. (The temperature change rate has some limitations depending on the temperature range.)

5. Conclusion

This article has looked at the features of the Fast Cycle Chamber and considered some of its applications. Due to its rapid temperature change rate, which can also be set by the user, this model opens a wide range of possibilities in various fields such as heat treatment and molding materials requiring efficiency and reproducibility in testing.

At Tabai Espec, we shall do our best to continue to provide products that meet the needs of our valued customers. If you have any comments or suggestions, please feel free to contact us at any time.



Temperature cycling and constant test, 60 h total test time			
Condition		Test results	Acceleration rate
120°C constant temp. exposure		0.1	Set as 1
Temperature cycle (60 cycles)	2°C/min.	0.35	3.5×
	5°C/min.	0.75	7.5×
	10°C/min.	0.79	7.9×
	15°C/min.	0.8	8.0×
	20°C/min.	0.8	8.0×

Source:D. Karam, “Burn-in: Which Environmental Stress Screens Should be Used”, RADC-TR-31-87, March 1981

Fig. 4 Relationship between temperature change rate and thermal stress strength

ESPEC

TECHNOLOGY REPORT

Pub. Date: April 1, 2000 (biannual)

Publisher: TABAI ESPEC CORP.
3-5-6 Tenjinbashi, Kita-ku, Osaka 530-8550, Japan

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Office of the editor, "ESPEC Technology Report",
TABAI ESPEC CORP.
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