Technical information for our customers

ESPEC

TECHNOLOGY REPORT

Special issue:
Evaluating Reliability and Humidity Measurement

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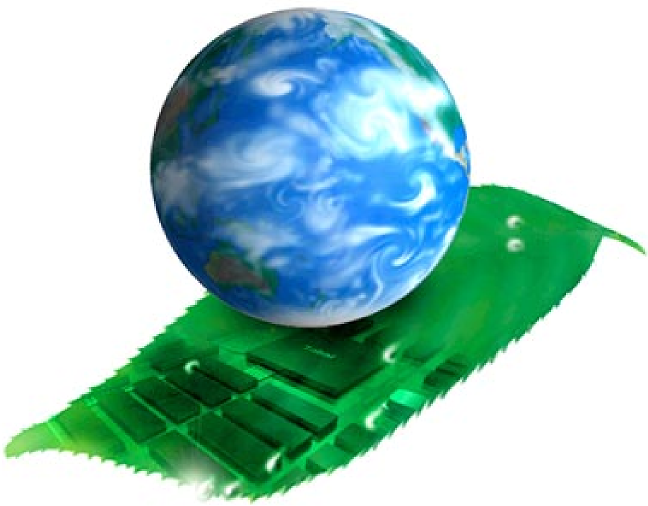

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TABAI ESPEC CORP.

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, 1998)
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:	608 (plus 65 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)
- Environmental Test Chamber Network, E-Bus

Measurement Evaluation Systems
- Ion Migration Evaluation System
- PWB conductor Resistance Evaluation System

Burn-in Test Systems
- ECL Testing Burn-in System
- Flash Memory E/W Cycle Test System
- Automatic Burn-in System

LCD Production Equipments
- Automatic Clean Cure System
- Single Loading Plate Clean Oven

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.

Understanding the Technology

Fundamental Concepts of Environmental Testing Techniques in Electricity and Electronics

Part 4: To carry out effective environmental testing

Toshio Yamamoto*

For the final article in this series, we would like to present a number of items for reference to aid in carrying out effective environmental testing. When environmental testing is done according to the manual provided, the work can at least be completed, but would it not be possible to go a step further and obtain one's own measures to carry out actual environmental testing more efficiently? Additionally, there are a number of smaller details that may not be major items within actual environmental testing, but are being overlooked. We would very much like to have testers check to see whether they are overlooking these points. We believe this will be time well spent. Effort invested in looking at environmental testing in this way and accumulating these small details will pay big dividends in future testing work.

Contents

1. Introduction

The establishment of modern environmental testing relies in large part on the Agree Report[1]. If the statement is limited to the field of reliability, the characteristic merit of environmental testing, the report set environmental testing methods for quantitatively measuring the transition to failure of products in a variety of environments encountered in product storage, shipping, and use. The report also quantified evaluation of accelerated life testing. As a result, it became possible to establish methods for quantitatively evaluating failure, and to clarify the relationship between product failure and the results of environmental tests and accelerated tests. This has promoted improvements in the reliability of industrial products, particularly in modern electrical and electronic products.

2. Environmental testing performed as reliability testing

In environmental testing, one type of reliability testing, you are surely aware that there are many types of testing other than temperature and humidity testing, but whatever the type, testing can be broadly classified as testing done within the range of the upper and lower limits (particularly the upper limits) of the environment of actual use, or as testing done under severe conditions that exceed the normal range of use. The first type, called simulation testing, imitates actual environmental conditions and needs no further explanation here. The second type is performed under severe environmental conditions and can be broadly separated into "accelerated testing" and "survey testing for weaknesses". However, from the standpoint of reliability, both require reproducibility[2] of test results performed under identical conditions, and both require the scientific compatibility to obtain identical results for the same test using different test equipment.

*Technical Planning Department

Testing performed under severe environmental conditions can be seen as either accelerated testing performed within the range to obtain results of the same failure mode occurring in the field, or as testing to seek out the weaknesses of the individual product, called survey testing for weaknesses. The latter form can produce failure modes that differ from those found in actual use.

The difference between these two types of testing is that accelerated testing can be seen as obtaining results with general social applications, while survey testing for weaknesses can be seen as done for research purposes for special environments (e.g., artificial testing conditions, locations, and time) that are not particularly applicable for society in general. Failure to understand this distinction can lead to mistakes in test performance levels and in combining test conditions that can result in mere destructive testing, so strict care must be taken on this point.

3. Key points for environmental testing and environmental stress

When environmental testing is done as accelerated testing, it is fundamental that only targeted environmental conditions be applied to the test specimens, and that no other stress be applied. However, in reality, stress outside the targeted conditions occurs quite often, so this point requires attention. In addition, targeted stress may not be occurring appropriately due to problems with measurement technology or technical misunderstandings, so prior study and preparations are crucial to controlling the test environment.

3-1 Temperature and humidity environments and excess stress

In actual test equipment, air in the test space is usually circulated by force using a fan. In such cases, wind velocity is not uniform among equipment manufacturers, and in some cases is not even uniform in different pieces of equipment offered by the same manufacturer. Sometimes different test equipment is used with no change in the type of test. In such cases a test must be run during the preparation period using dummy specimens to check whether any differences in stress occur even under the same environmental conditions. One must not be confused by apparent temperature and humidity indications or conditions. Even in a simple temperature test, the test environment required by the test consists not of the apparent temperature, but of the stress environment applied to the specimen as thermal energy, in which ideally the test space can be assumed to be homogenous. Thermal conductivity of test specimens differs according to the surface conditions and shape of the specimen, but basically conductivity is determined by air characteristics and wind velocity, and so wind velocity has a major impact as a parameter that fluctuates. Normally, in proportion to wind velocity conductivity is raised to power in the range from 1 to 1.25.

On the other hand, most temperature and humidity testing equipment uses a system constructed so that water is heated in a humidifier provided in the chamber, the resultant steam is sent into a dehumidifier, which condenses excess steam and returns it to the humidifier, and then the required amount of steam is mixed into the circulating air and forced into the test chamber with a powerful fan. The specimens are constantly exposed to fresh moist air for testing. One point requiring attention in humidity testing using this type of test equipment is that comparatively large droplets of water condensed by the dehumidifier or splashing up from the surface of the boiling water in the humidifier can ride the strong air currents into the test chamber. The stronger the air currents, the greater the quantity, and the danger of a large quantity of water droplets getting into the air currents is particularly great during the temperature and humidity ramp-up, in the stage going from the initial test chamber environment until the humidity setting is reached. As a result, these water droplets fall onto the surface of the specimens, giving them a higher moisture level than the vapor setting. For example, if water droplets fall between the exposed terminals when testing specimens such as surface-mounted multiple pin IC's, the dielectric strength is seriously weakened, cross-linking is formed, and breakdown occurs. This type of phenomenon affects test reproducibility and can lead to mistaken test results. Most current test equipment lacks the ability to cope with this defect. Because of this, the tester must use a practical test technique such as ramping up the temperature in advance and raising the surface temperature of the specimens above the dew point temperature before ramping up the humidity, or else arranging the specimens in the chamber in such a way that water droplets from the air currents are not so likely to fall on them.

3-2 Key points in HAST

Let's consider HAST (Highly Accelerated Stress Test) as a typical example of accelerated testing. The HAST test method was developed to speed up the evaluation of humidity endurance of specimens such as electronic parts sealed in plastic. This is a highly accelerated test using extremely severe stress conditions that far exceed the environmental endurance rating of the specimen. In such conditions, the occurrence of unwanted stress can easily lead to major errors in the test results. Because of this, even more care is required than in normal temperature and humidity testing. If we do not strictly control the occurrence of unwanted stress, our ability to obtain reproducible results becomes very uncertain.

Especially with this level of severity of test conditions, the test method may be unsuited to some specimens due to their materials, construction, or equipment type. Furthermore, the test method may produce failure modes that greatly differ from those found in the field, and we cannot say for certain to which specimens this method can be applied. Because of this, we must study carefully in advance whether this method is suited to our purposes. For these reasons, we must be aware of the fairly limited range of application of this type of test.

When selecting test equipment for environmental testing above 100°C, we must select equipment with superb performance in temperature and humidity control or face uncertain reproducibility. Environmental control becomes particularly critical with humidity levels near 100%, where a difference of ±0.1°C means the difference between a saturated and an unsaturated environment, or in some cases a super-saturated environment, soaking the surface of the specimen in water.

By the way, the nature of most products results in a conflict between resistance to high heat and resistance to humidity: raising one tends to lower the other. It is crucial to confirm whether this property exists in individual specimens, and it is essential to fully study the product construction and material in regard to performing a test.

3-3 Temperature cycle testing and thermal shock testing

Generally, no clear distinction is made between temperature cycle testing and thermal shock testing, although quite often tests using air as a heat transfer medium are called temperature cycle tests, while those using a liquid medium are referred to as thermal shock tests.

Whether the heat transfer medium is air or a liquid makes a big difference in the time period of thermal stress, and from the standpoint of thermal conductivity, thermal shock testing is the more severe. The problem, as expressed in section 2, is the lack of clarity about whether this test is an accelerated test or a survey test for weaknesses. Regardless of how it is seen, thermal shock testing has a strong tendency to be used as a survey test for weaknesses.

Next, let’s look at temperature cycle testing from the standpoint of how it handles reliability.

In its usage environment, a product is exposed to daily temperature fluctuation as well as temperature fluctuation from being turned on and off, resulting in mechanical fatigue induced by temperature fluctuation. Except for heat-generating parts, generally this temperature fluctuation is sluggish, there is only a slight temperature differential between the inner section and the surface of the electronic part, and mechanical stress results from the conflict between structural materials and shape. Temperature cycle testing corresponds to these conditions and can be understood as repeating the accelerated conditions in a short time period and increasing the temperature differential to increase the severity of stress. Therefore, this can be understood as pure and simple accelerated testing. To further reduce testing time, the temperature gradient must be increased, but creating too great a temperature differential between the inner section and the surface of the electronic part introduces the possibility that this will no longer be essentially a temperature test. The limits of the temperature gradient depend on the product type and size, and so we must be careful not to assume that creating an excessive temperature differential will result in accelerated testing.

On the other hand, in thermal shock testing, a sudden temperature change is applied to the surface of the test specimen, creating a temperature change gradient between the inner section and the surface of the electronic part in a very short time, and can be understood as an attempt to evaluate thermal shock. However, this can be applied to testing parts for special applications (e.g., electronic parts built into airplanes that repeatedly undergo rapid raising and lowering) and to testing to flush out weaknesses for parts with limited purposes in a limited range during the manufacturing process. We must be aware that basic to this testing is the fact that the level of test conditions will depend on the size, shape, and especially the thermal capacity of the test specimen.

In either type of test, the factors causing temperature changes in the test specimen itself consist of the air or liquid temperature around the specimen, the wind velocity or current flow rate, the thermal capacity and conductivity of the specimen, and the shape and surface condition of the specimen.

4. Key points in performing environmental testing

When performing environmental testing, it is natural that the manner of progressing the test will depend on the purpose of the test. For example, the method of product failure analysis can be selected from among various methods depending on whether it is for academic purposes, i.e., a method of analyzing product failure, or for simple routine business such as lot inspection of manufacturing products or acceptance testing of purchased parts and externally ordered parts.

Particularly in the case of academic purposes, to perform testing effectively, a little attention affects validity. For example, there are matters such as testing products of different companies simultaneously, or making observations taking care for changes and abnormalities that are not related to current test results. As a result, when examining the test specimens closely after the test has been completed, quite often not only failure precursors, but also abnormal failures are found, making it clear that the test facilities or the test method were not appropriate. Also, after the test has been completed, it may seem that no abnormalities have occurred, but upon disassembling and analyzing the specimens they may be right on the verge of failure.

Considerations when performing these types of tests include:

(1) How much interest does the tester have personally in the test?
(2) Does the person in charge of development have a serious concern in the reliability of the specimens to be tested?
(3) Is the tester experienced in reliability testing?

Matters such as these directly and indirectly affect the persons involved. When factors related to the persons involved accumulate, we can express the result as know-how, and they make up an aggregate of know-how for specific tests. (In one sense, there is no method involved, but this know-how should be appropriately passed on to one’s successor.)

On the other hand, when performing testing as a matter of routine business, most tests are handled as general standard tests regardless of whether public or private. This has brought about a situation in which it is impossible to understand the actual purpose of the testing being personally attempted, and standard test methods are applied automatically. Actually, even in an IEC standard test method used in public standards, there always exists a background to that test method, and it does not exist as vague standards. In other words, background information and general information and guidance explain the background. The structure of the IEC60068 series has the following basic form.

Part 1: General information and guidance
Part 2: Tests
Part 3: Background information
Part 4: Information for specification writers
Part 5: Guide to drafting test methods

Currently, these are not provided fully in each individual test method, but they cannot be overemphasized.

To return to the original subject, if we make a conjecture as to how this state of affairs has come about, we can assume that it has come about against the background of test work becoming more strongly characterized as standard work with the spread of quality control activity, with even those lacking knowledge in the field of reliability being able to perform tests (as work).

Opinions on how a variety of test methods should be applied will depend on the standpoint of the manufacturers and users (e.g., acceptance tests vs. delivery tests). Also, in many cases test methods that are called by the same name differ greatly from the standpoint of the particular field of technology (e.g., electric, electronic, machinery, or the chemical industry) for comparable products. Therefore, when differences exist in particular fields of technology, mutual understanding of terms must be agreed upon for use in the pre-contract stage of negotiations. Because of this, we must be aware that sometimes we must spend sufficient time to resolve problems in advance before the testing contract is put into effect.

5. Practical use of standard tests

At this point, we will take up the use of IEC standards as public test standards.

We have already pointed out the impossibility of prescribing standard environmental tests that can be applied comprehensively to all individual products. However, it is possible to suggest tests that are appropriate to a large number of products. (Surely, the IEC test standards can be seen as being for this purpose.) Also, when modifications are made to adapt conditions to specific environments, the modified conditions must be clearly presented when planning the test.

When selecting a test method, we must be aware that the values for test conditions (test severity) within the standards are merely representative values rather than environmental conditions actually encountered by the individual products. If certain products are known in advance to encounter environments exceeding the conditions given in the standards or to have special endurance, testing with fixed conditions can of course be eliminated. For example, if the conditions in a storage test have been covered in the shipping test, it would make little sense to go ahead and carry out the storage test.

Next, let’s take a look at the purposes for different tests.

(a) Storage testing

Storage testing is based on the environmental conditions to which the product is exposed during the continuous time period when it is stored. However, in the standards, storage refers to the time from product manufacture until initial use, excluding the time during shipping.

The product should be tested under conditions occurring during storage, but for example if the product is in packaging during storage, as a rule it should be in packaging during testing. Also, if the product is stored in both packaged and non-packaged states, it must be tested in both states. We must remember that for certain types of test conditions and products, testing conditions are more severe with the product in the packaged state than when the package has been opened. For example, when products are hermetically sealed in packaging and vapor is trapped inside the packaging, we must remember that temperature changes can cause dew condensation. Also, a puncture in the seal can lead to a phenomenon called breathing, in which humidity from the surrounding air is pulled into the package.

(b) Shipping testing

Testing for shipping is based on the environmental conditions to which the product is exposed during the time period when it is being shipped. Shipping can be done over land, on the sea, or in the air. We shall use the term shipping to refer to the time in which the product is transferred from one site to another after being shipped from the manufacturing plant.

Products are tested under shipping conditions applicable to the individual product, and if a product is shipped in the packaged state, it should be tested in the packaging, and if some items are shipped without packaging, testing must be done in both states, the same as in (a) above.

(c) Usage condition testing

Usage conditions include every condition to which a product is exposed during its life cycle, including product usage, down time, maintenance, and repairs. However, the environments inside the individual product equipment should excluded in this case, and determined separately.

Relevant specifications set details such as whether a product should be operated during environmental testing, and the need for measuring before, during, and after testing. The sequence of these tests is also prescribed in relevant specifications. Combining various pre- and post-tests with the targeted testing obviously has some merit, but creating too unique a sequence can require excessive concern with suitability, and care must be taken with excessively increasing the expense of testing.

(d) Test (exposure) time

Test time (recommended duration) is prescribed in the standards, and this value can be understood as a value backed by full experience in confirming results on products at the time the standards were established. Therefore, when a lot of time has elapsed since the standards were established, they may not be appropriate to the current level of technology, or they may serve a different purpose, so the values in the relevant specifications are given priority.

(e) Combined testing

Combined testing can obtain results that more accurately reflect actual environments than can individual tests done serially. However, we would like you to realize that combined testing doesn't achieve validity until you clearly understand the combined conditions that should be anticipated within the dynamic environment.

6. Guidance for test planning

At this point we would like to think beyond the limitations of tests for individual environmental factors such as temperature and humidity, and consider instead environmental testing within the relationship between the product and its broad natural environment.

(a) Climate testing

Reproducing all the various phenomena of the real natural world in a limited space such as a test chamber or test equipment is absolutely impossible. The most realistic approach is to construct environmental factors such as temperature and humidity and create individual test environments. The IEC60721 series will serve well to explain complex combinations of conditions found within a typical environment.

Various elements within a wide variety of environments are themselves difficult to reproduce, or the reproduction may not be realistic due to the complexity. Therefore, the realistic approach is to carefully study the affects of each factor in advance, and each affect must be clarified in advance to the fullest possible extent.

(b) Exposure to the sun

Specific environmental testing for general exposure to the sun's rays is not covered in the IEC60068 series. In most cases, an imitation sun spectrum is used in testing for exposure to sunlight. However, actual problems include various restrictions within the test chamber as well as extreme difficulty in imitating sunlight exposure within the test equipment. The technique developed for that purpose is to create a spectrum test divided into the three spectral bands of infrared, visual, and ultraviolet light. Then, sensitive products are assessed in these individual conditions and tests are performed in accordance with specific purposes.

We will present for reference three major phenomena caused by exposure to sunlight.

1) Ultraviolet rays and photodegradation

Most of these affects occur in the ultraviolet spectrum. However, similar affects are known to occur in the visual spectrum as well, so we must be careful. Examples of these influences can be found in fading and in fogging of semi-transparent plastic. Most tests to evaluate these affects can be done at the level of materials and parts, and are also possible for completed products. With completed products, increased heat absorption and heat rises within the product itself add to the results such as causing color paint to fade.

2) Thermal effects

The following methods are used to evaluate individual products in regard to the determination of durability and failure mechanisms in relation to rising temperature.

i) Temperature rise

The sunlight load causes a marked rise in the surface temperature of the product and its immediate vicinity compared to the ambient temperature. There are two ways to imitate this temperature rise. One is to use the 15°C rule (the amount of temperature rise determined from experience). The other is to use a heat lamp to raise the surrounding temperature.

ii) Thermal gradient

Sunlight irradiation comes from a single light source, so the thermal effect in the open environment is directional rather than equal. Therefore, different thermal affects are received on different parts of the exposed product. This sectional heating up exceeds the tolerance for temperature differential of the product and causes sections of the material to expand. This causes problems such as defects in the seal and changes in the performance of electronic parts. To handle these problems, a directional irradiation heat source is promoted. Then, when imitating this condition, a section inside the product with an unrealistic temperature rise must be avoided by maintaining appropriate air circulation.

c) Mechanical environments

In most cases mechanical environments are induced or artificial environments rather than natural environments. Testers must exercise due care in analyzing each element in the life cycle profile in the mechanical environment applying such stress as vibration, shock, and noise to the product.

1) Vibration testing

Sine wave vibration testing is limited by measurement methods and testing limitations, but historically it has been applied to most products. On the other hand, in most cases random vibration is becoming used for diverse applications as a test that can recreate conditions realistically. Sine wave vibration produces limited conditions (e.g., products containing rotating parts, such as rotors or airplane propellers), but, contrary to past circumstances, sine wave resonance investigation should already be considered as being at a level unsuited to current investigation.

2) Shock testing

Shock testing is applied to products exposed to comparatively rare, non-repetitive circumstances encountered during operation, shipping, or use of the product. This measure is applied to cover product brittleness encountered by every package in these environments.

Typical affects of shock include the following.

a) Permanent damage due to overload
b) Sudden damage to or fatigue of materials
c) Failure due to changes in friction or impedance between parts.

7. Summary

Environmental testing varies according to the different purposes to which it is applied. Even when tests are called by the same name, in many cases they will differ to some extent because of the test details. This situation even applies to tests that conform to public test standards, and in this type of situation the success of the test can depend upon the information exchanged by the tester and the party requesting the test, as well as their mutual understanding. Acquiring a wealth of experience in performing tests is extremely important, but in many cases this can result in the tester jumping to a hasty conclusion about the gist of what the party requesting the test wants, and as a result missing the most important aspect of the test. As an act of performing work, the test can be run merely by following the manual, but in reality the tester must acquire the habit of looking at the details of the test theoretically from a scientific standpoint. Even in that sense, the test varies from the script each time, and we would like to encourage leaving a written record of each test. Accumulated know-how also can be theoretically supported, clarifying the scientific basis by the process of rereading these records. This can help one to clearly grasp key points that must be caught. This is the main point of "effectively performing environmental testing".

1) **AGREE Report**: Advisory Group on Reliability of Electronic Equipment, report established August 21, 1952 (US Dept. of Defense)
2) **Reproducibility**: Proximity of individual results obtained with identical test specimens and testing methods under differing conditions (different testers, different tools and equipment, different test sites, or different time period)
3) **Repeatability**: Proximity of test results continuously obtained with identical test methods, identical test specimens, and identical conditions (same testers, same tools and equipment, same test site, and same time period)
(Above definitions from ISO3534/3 Statistics: Terms and Symbols, in Part 3, Test Planning)

Report 1

An analysis of solder cracking mechanisms

Hiroko Inoki* Hirokazu Tanaka* Yuuichi Aoki* Shigeharu Yamamoto*

High-density mounting of circuit parts on electronic equipment makes the reliability of solder joints more crucial than ever. To grasp trends and improve reliability in solder joints, studies must be undertaken on printed circuit boards, mounted parts, and mounting technology. Solder cracking is directly involved in equipment failure, and controlling its occurrence has become a major problem.

This report looks at one cause of solder cracking—the roughening of the solder grain boundary field—and verifies the relation of the problem to both thermal and mechanical stress. The results indicate that the solder grain boundary experiences roughening from both types of stress, although thermal stress exerts the greater influence. Degradation of solder strength due to roughening was also confirmed.

1. Introduction

Solder is used to join many of the circuit parts in modern equipment, and maintaining the reliability of solder joints is crucial to maintaining the reliability of electronic equipment. However, use of miniaturized electronic equipment in recent years has brought the equipment into contact with a wide variety of environmental conditions leading to a wide range of external stress, which can lead to solder cracking.

Because of this, this report will detail the following studies on the relationship between stress and the roughening of the grain boundary that leads to solder cracking:

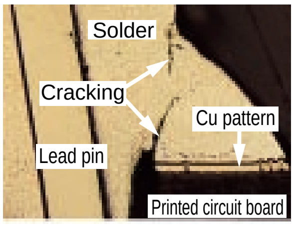
(1) An investigation of the solder load and stretching caused when mechanical stress is applied to solder joints,

(2) An investigation of the changes caused in the solder grain boundary when load fatigue is applied to solder joints, and

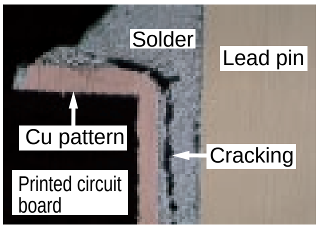
(3) An investigation of the changes in the solder grain boundary caused by thermal stress, as well as how changes in the grain boundary affected the strength of solder.

2. Mechanisms of solder cracking

Solder cracking can occur either internally within the solder or in the area where the solder joins to another surface. Both types of cracking have been confirmed to commonly occur in the field, and are a major cause of eletronic equipment failure. (Photo 1, Fig. 1)



(a) Solder internal cracking in electronic equipment left outside for 5 years (IC lead section)



(b) Solder joint surface cracking at connector lead pin

Photo 1 Failures occurring in the field

Internal solder cracking is caused by roughening of the α phase (Pb rich) of the solder structure. This occurs when the α phase roughening is promoted by thermal energy of temperature cycles. When stress is applied, cracks are thought to grow at the grain boundary surface within the grain boundary of the α phase and the β phase (Sn rich).[2), 3), 5), 6), 7)] (Fig.1 section (1), Fig. 2)

Solder joint surface cracking occurs primarily in the vicinity of layer roughening at the solder joint surface of the intermetallic compound. (Fig. 1 section (2))

*Environmental Test Technology Center

When the metallic layer of the intermetallic compound grows and thickens due to high temperature, fine cracks appear in the solder joint layer, making it less resistant to shock, and giving the solder a tendency to peel.[4] However, it has also been reported that in actual use the intermetallic compound does not cause cracking.[5]

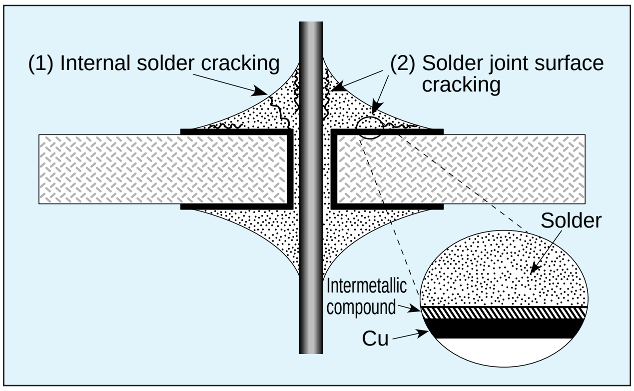


Fig. 1 Forms of solder cracking

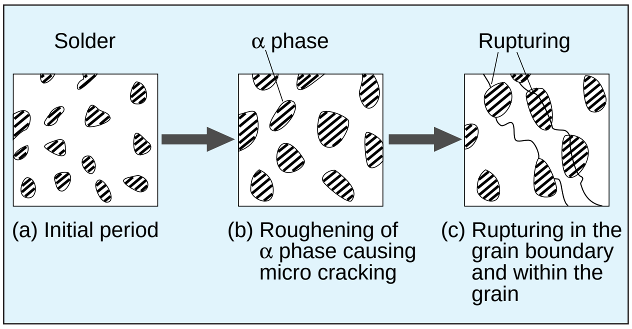


Fig. 2 Solder cracking mechanisms (solder internal cracking)

Reported countermeasures for solder cracking include such means as the following.

(1) By adding Ag, In, and Sb to the solder, the additive elements (Ag, In, and Sb) diffuse throughout the grain boundary of the Sn-rich phase and the Pb-rich phase, and the resulting intermetallic compounds (In-Sb and Ag-In) control the diffusion of Sn.

(2) A metal such as Ni is used as a non soldering joint material with a slow rate of growth between the Sn and the intermetallic compound, suppressing roughening of the Pb-rich phase in the vicinity of the solder joint field surface, and thus improving fatigue life.[6), 8)]

3. Results and discussion

Testing was performed for the following:

(1) Roughening of the grain boundary due to mechanical stress, and

(2) Roughening of the grain boundary due to thermal stress.

The two types of stress were compared in regard to their influence on the grain boundary.

3-1 Specimen

The specimen was a flexible copper wire passed through the through hole of a copper plated glass epoxy printed circuit board and soldered with solder dip (63 Sn wt%) for 10 seconds at 260°C. Fig. 3 shows the arrangement of the specimen.

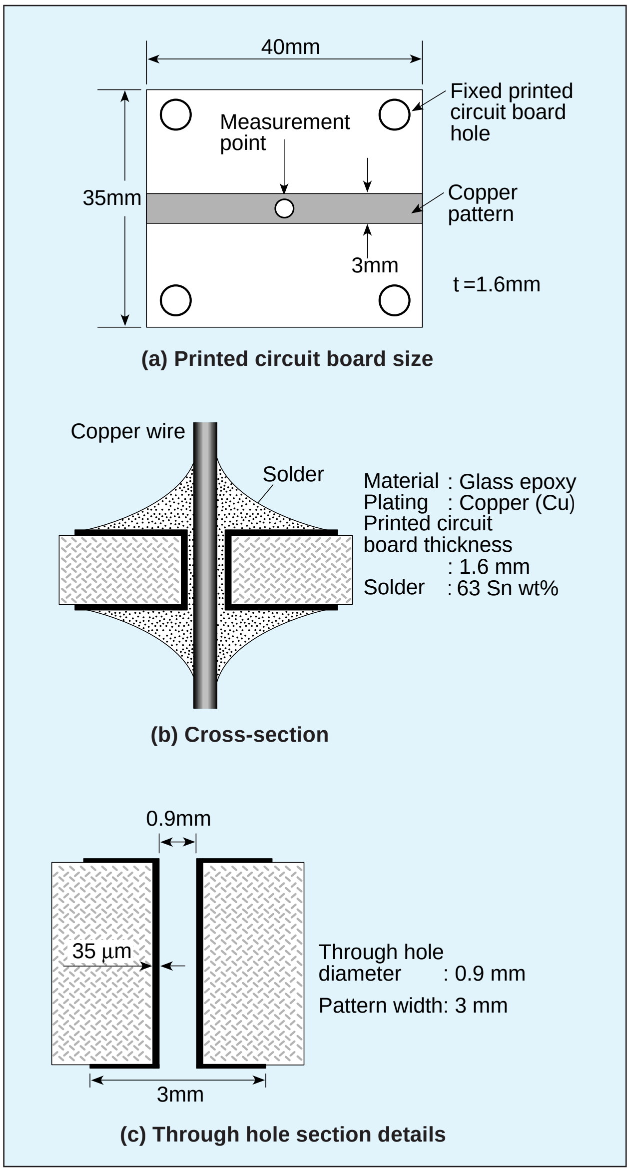


Fig. 3 Specimen for tensile test

3-2 Testing for roughening of the grain boundary due to mechanical stress

(1) Experiment 1: Tensile testing (the relationship between load and solder elongation)

To determine the testing conditions under which mechanical stress is applied to the solder, tensile testing was performed on copper wire of various diameters. Table 1 shows the test conditions, and Fig. 4 shows the test equipment. The method consisted of using a load cell to measure the load applied to the specimen, and then analyzing the load characteristics.

Table 1 Tensile testing conditions

Test conditions	Copper wire diameter (mm)
Stretching speed = 0.3 mm/min	ϕ 0.45, ϕ 0.55 ϕ 0.65, ϕ 0.80

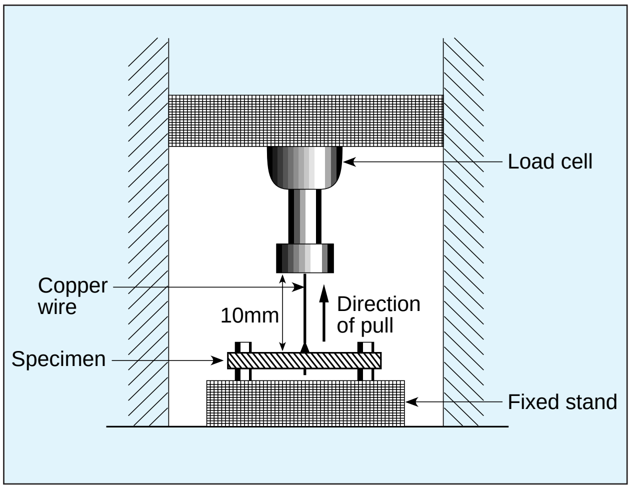


Fig. 4 Tensile testing equipment

Fig. 5 shows the test results. The larger the diameter of the copper wire, the greater the load endurance until the copper wire finally breaks. Breaking occurred at around the middle of the length of all the copper wires. In the initial stage, all copper wires, regardless of the diameter, showed a consistent trend. This can be thought of as the elongation of the solder, copper wire, and printed circuit board.

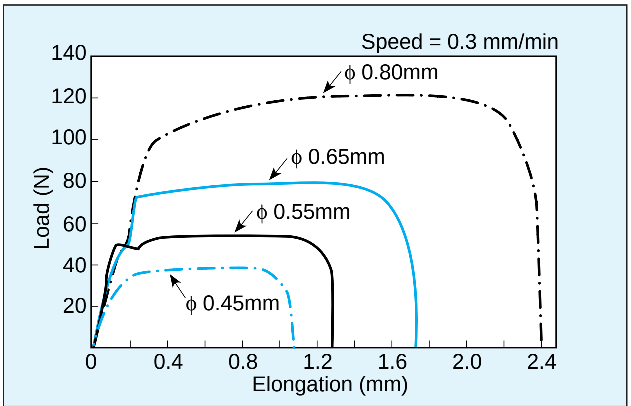


Fig. 5 Load-elongation diagram for copper wire diameters

Fig.6 shows the load-elongation diagram for the initial stage of the ϕ0.55 mm copper wire. The elongation amount up to about 0.2 mm in section (1) shows a consistent trend, then in section (2) it shows a declining trend, and finally in section (3) it shows an rising trend once more.

In section (1), the external force is within the flexibility limit, so the flexibility prevents distortion. If the external force is removed, the object returns to its original shape. However, when the external force exceeds the flexibility limit in section (2), the relationship between stress and distortion suddenly changes, slipping occurs, and large, marked stretching occurs. As external force is applied again in section (3), tensile resistance can be assumed to increase gradually until breaking occurs.[1)]

These results indicate that when applying stress to solder, the stress must remain within the range of region (1) when applying load to the solder joints.

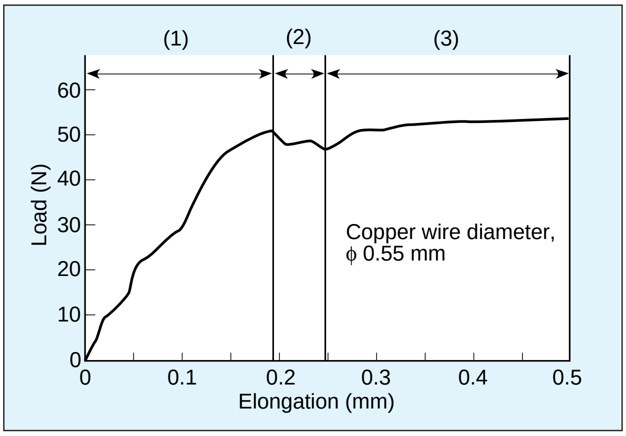


Fig . 6 Load-elongation diagram (Initial stage)

(2) Experiment 2: Load cycle testing

To investigate the relationship between cracking and cyclic stress, we performed load fatigue testing.

For test conditions, the results of Experiment 1 were used to determine the cyclic load. In addition, the test speed was set at 3 mm/min as an appropriate value for applying stress to the soldered section.

These values were determined according to the following preliminary tests.

(1) At test speeds exceeding 10 mm/min, the sudden change caused stress to the specimen that exceeded the test condition load (29.42N), resulting in the copper wire breaking.

(2) Using the same speed as the tensile test (0.3 mm/min) required excessive testing time.

Therefore, preliminary testing was performed in the range from 0.3 mm/min to 10 mm/min, and the appropriate speed was set at 3 mm/min.

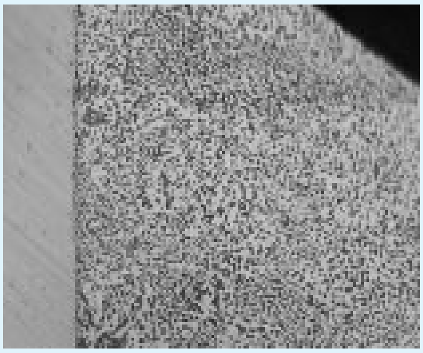
Testing was done at 0, 10,000, and 100,000 cycles, and cross-sections were observed after each test, and the condition of the solder grain boundary was compared.

Table 2 Load fatigue test conditions

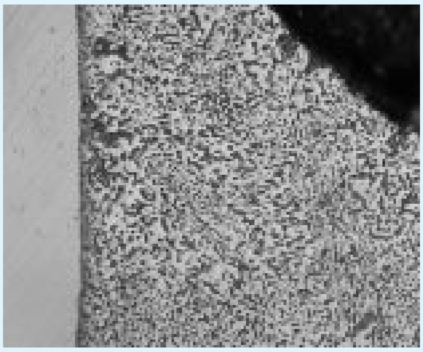
Load	0 ↔ 29.42 N (≒3kgf)
Number of cycles	0, 10,000, and 100,000 cycles
Temperature and humidity conditions	Room temperature and humidity

Photo 2 shows cross-sectional surfaces after load cycle testing.

In the load fatigue testing, cracking was confirmed at around 40,000 cycles. Furthermore, cross-sectional observation confirmed roughening of solder sections where greater stress was applied.



(a) Initial



(b) After 10,000 cycles

(c) After 100,000 cycles

Photo 2 Cross-sectional observation after load fatigue testing (200×)

3-3 Testing for roughening of the grain boundary due to thermal stress

Solder is an alloy with a low melting point, and so even at room temperature roughening can easily occur in the solder grain boundary.

However, higher temperatures accelerate the roughening of the solder grain boundary, and the speed of growth of the intermetallic compound also increases. As the grain boundary becomes larger, solder becomes less resistant to thermal stress, and since the intermetallic compound is mechanically fragile, it has low resistance to stress in the direction of the interface.

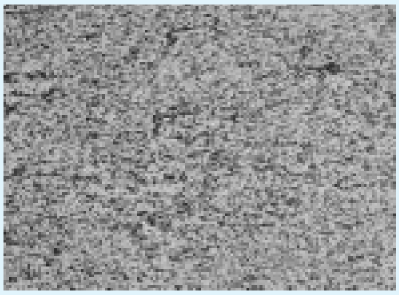
Because of this, we tested the relationship between thermal stress and the roughening of the grain boundary.

Experiment 3:
Tensile testing after exposure to high temperature

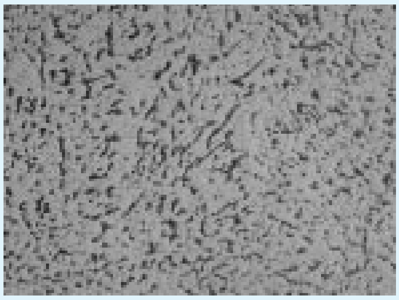
To accelerate thermal stress, specimens were exposed to a 150°C atmosphere for 100 hours and for 200 hours. Photo 3 shows the results of cross-sectional observation.

The results confirm that the longer the exposure to thermal stress, the greater the roughening of the grain boundary.[2)]

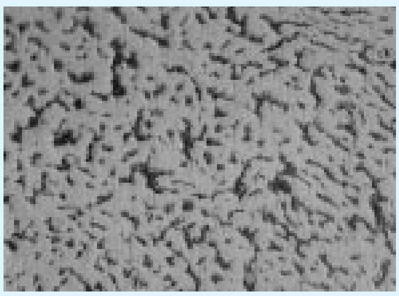
Mechanical stress caused roughening only in the sections to which stress was applied, but after exposure to high temperature, the entire grain boundary showed roughening.



(a) No high temperature exposure



(b) After 100 hours of exposure



(c) After 200 hours of exposure

Photo 3 Cross-sectional observation after exposure to high temperature (200×)

To confirm the solder strength of specimens exposed for 100 hours and 200 hours, tensile testing was performed using the test conditions given in Table 1 and the test equipment shown in Fig. 4. Solder strength was measured and load change characteristics were analyzed.

Fig. 7 shows test results. The changes in solder load characteristics after high temperature exposure show that the longer the exposure to high temperature, the greater the stretching of the solder.

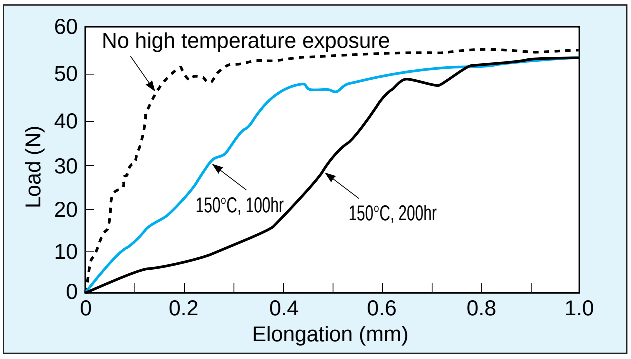


Fig. 7 Roughening of the solder grain boundary and changes in load characteristics

4. Conclusion

(1) In these tensile tests using specimens, the characteristics of the load on the soldered section can be separated into three regions. These experiments show the necessity of testing within the region prior to the occurrence of solder slipping.

(2) With mechanical stress, roughening of the solder grain boundary occurred only in the sections bearing the stress. However, with thermal stress, roughening occurred throughout the entire solder grain boundary.
These results confirm that thermal stress has a greater influence on roughening of the solder grain boundary.

(3) The tests show that roughening of the solder grain boundary causes greater stretching of the solder, and degrades mechanical characteristics.

Solder joints are a vital technology supporting electronic equipment. However, the occurrence of solder cracking causes failure of electronic equipment. From the standpoint of product safety as well, as reflected in the recent enactment of the product liability law, maintaining reliability is crucial.

The authors observed the relationship between the cracking in solder joints and the changes in the grain boundary, and so performed these experiments. As a result, changes were confirmed in both thermal and mechanical stress, and were also confirmed to be a factor in degradation of the reliability of solder joints.

These types of external stress are certain to occur in the environments in which electronic equipment is used, and if conditions such as shock, vibration, and temperature cycles were added, they would cause complex interactions that would accelerate degradation. It is vital to thoroughly comprehend the types of stress actually occurring in the usage environments and to build reliability into the equipment at the design stage.

[Bibliography]

1) Wakichi Tanaka, “Soldering Technology”, Sogo Denshi Shuppan, (1974)
2) Hirokazu Tanaka, Yuuichi Aoki, Shigeharu Yamamoto, “The Mechanism of Solder Cracking”, ESPEC Technology Report No.3, (1997)
3) Yuuichi Aoki, Hirokazu Tanaka, Shigeharu Yamamoto, “Reliability of soldered connections by temperature cycling test and thermal shock test”, Proceedings of the 23rd. Union of Japanese Scientists and Engineers Symposium on Reliability and Maintainability, (1993)
4) Masayoshi Kitamura, Seiji Yanagida, “The Mechanisms of Soldered Connection”, The Journal of Reliability Enginnering Association of Japan, (1996)
5) Seiichi Matsushige, Hiroshi Nakayama, Hiroshi Kondou, Kimitoshi Murata, “Concept of Accelerated Life Test”, Proceedings of the 21st. Union of Japanese Scientists and Engineers Symposium on Reliability and Maintainability, (1991)
6) Mitsuo Nakamura, Kenichi Kawai, Yasuyuki Tanaka, Eiji Asada, “The Concept and Example of Extension of Fatigue Life of Solder”, Proceedings of the 23rd. Union of Japanese Scientists and Engineers Symposium on Reliability and Maintainability, (1993)
7) Hirofumi Murata, Akio Yoshida, Tamotu Ishikawa, Keiji Asaha, “The Study of Reliability for Soldering on Surface Mount Device”, Proceedings of the 19th. Union of Japanese Scientists and Engineers Symposium on Reliability and Maintainability, (1989)
8) Yasuhisa Yamachi, Koushi Kimura, Kazuya Fujita, Takamichi Maeda, “Estimation of the Strength of Solder Joints and the Measures of its Deteriorate Strength”, Proceedings of the 24th. Union of Japanese Scientists and Engineers Symposium on Reliability and Maintainability, (1994)

Report 2

Humidity measurement and psychrometers in environmental testing equipment

Hirokazu Nakahama*

The use of psychrometers to measure humidity in environmental testing equipment is practically universal. No other thermometers are available that can stand up as well to the severe usage conditions of environmental testing equipment. While some features need to be improved, the construction of the psychrometers is simpler and more reliable than any other type of humidity sensor. Because of this, we discuss features of psychrometers such as construction, working principles, precision, factors of error, reliability, and points for caution in use. We also mention various related standards. Finally, we also examine functions required for humidity measurement in environmental equipment and future trends.

1. Introduction

Temperature and humidity equipment is used quite commonly in environmental testing equipment. Temperature and humidity are combined as environmental conditions used in testing, and many types of equipment, such as the Temperature/Humidity Cycle Testing Chamber and the Stability Testing Chamber, are geared to this type of test application.

Methods for measuring temperature are comparatively easy to understand, but humidity is unexpectedly troublesome. Humidity fluctuates according to temperature and pressure, and must be considered in conjunction with those phenomena.

Because of this, we would like to examine humidity measurement methods, and psychrometers in particular, used in environmental testing equipment.

2. Indicating performance in environmental testing equipment

2-1. Standards for environmental testing equipment

Within environmental testing equipment, performance standards (JTM standards) for Temperature and Humidity Chambers and Temperature and Humidity Rooms are set independently by the industry group the Japan Testing Machinery Association (JTMA).[1), 2)]

To enact JTM standards, the JTMA has performed a broad range of investigative research.[3), 4), 5)] Within this research, in cooperation with the Electrotechnical Laboratory of the Agency of Industrial Science and Technology, experiments were performed on thermometers used to evaluate chamber performance. Foreign standards were also consulted, BS in particular.[6), 7), 8)] These BS standards have now been abolished. Moreover, to adopt developments in the latest peripheral technology, JTM K-01 was revised in 1998 based on international investigations.[9), 10)] These revisions included changing the title.

The purpose of JTM standards is not to standardize the test equipment, but rather to provide a reasonable basis for consultations between equipment manufacturers and users and to provide a fair basis for evaluating test results. The main items are concerned with methods of indicating and evaluating performance in relation to temperature and humidity fluctuation and temperature and humidity uniformity. Fig. 1 shows a thermometer for evaluating the chamber performance adopted in JTM standards. The JTM standards do not establish any specifics concerning the construction of thermometers for evaluating chamber performance. Rather, they establish the use of the psychrometer and the psychrometric formula and the wind speed when using the psychrometer.

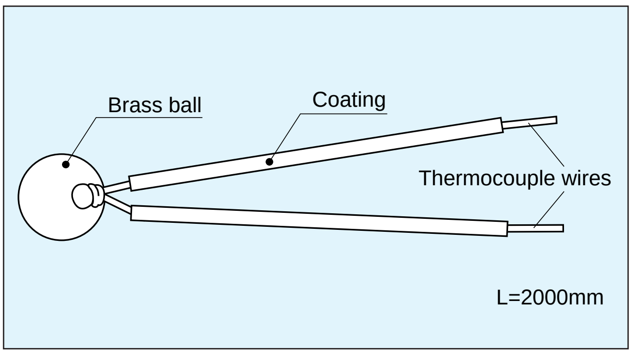


Fig. 1 Thermometer for evaluating equipment performance, JTM K-01, 03

*Technical Center

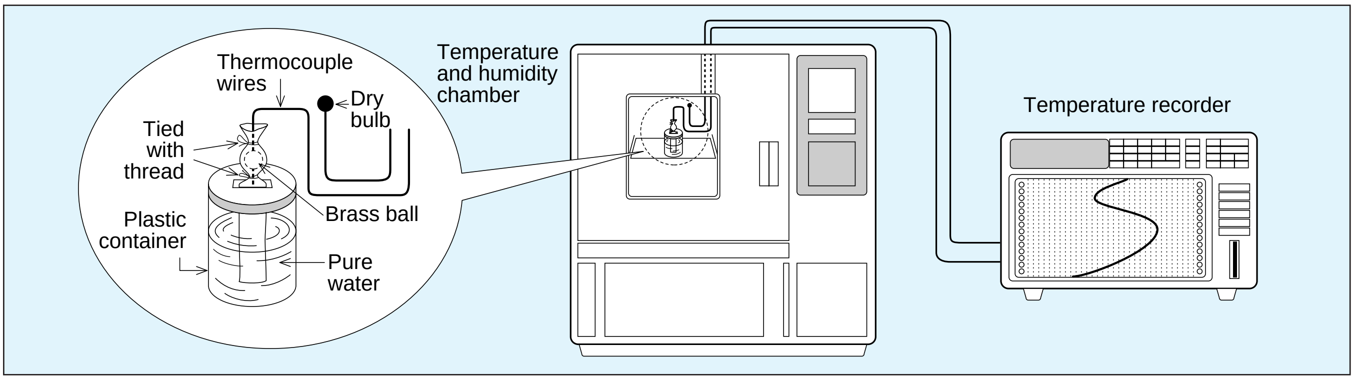


Fig. 2 Measuring temperature and humidity to evaluate equipment performance

Fig. 2 shows an outline of the humidity measurement for the evaluation method used at Tabai Espec. A plastic container (such as an empty 35 mm film canister) is used as a water pot, and a sleeve cloth (called a wick) is put over a thermocouple (type T) to detect wet-bulb temperature. To improve adherence between the wick and the thermocouple and the time constant adjustment, a 5 mm diameter brass ball is soldered to the temperature measuring junction of the thermocouple (type T). Therefore, as a thermometer, this device is the same as the one shown in Fig.1.

Equipment is nothing more than a means to attain functions and environmental conditions required for environmental testing, so each manufacturer should be continually adding improvements to the equipment design constant and the equipment construction depending on the users' requirements.

2-2 Performance indication of temperature and humidity

The temperature and humidity performance items specified in the catalogs and specifications differ depending on the type of equipment. The main items include temperature and humidity control range, temperature and humidity fluctuation, temperature and humidity uniformity, and the temperature heat-up/pull-down rate. These definitions and measurement conditions are established in the JTM standards.

The fluctuation and uniformity performance of temperature and humidity shows performance in a stable condition. The area of equipment performance in which a disparity tends to occur is performance in transitional conditions. This includes such matters as the smallness of the amount of overshooting and undershooting when attaining temperature and humidity settings, and the smallness of the disparity from the setting gradient when operating in ramp mode. Stability of performance is also crucial when defrosting refrigeration circuits and in poor surrounding conditions. Manufacturers are constantly striving for quality in dynamically controlled performance in these areas. However, these are not normally written in the specifications. It is difficult to specify them as standard performance items, and there seems to be no good means of displaying them as performance data.

2-3 Hygrometers and the range of temperature and humidity

One of the main products in the Tabai Espec line-up is the line of temperature and humidity chambers called the Platinous Series, which has achieved sales of approximately 30,000 units since being put on the market in 1969. Fig. 3 shows the basic construction, and Fig.4 shows an example (for PDR and PDL) of the temperature and humidity control range.

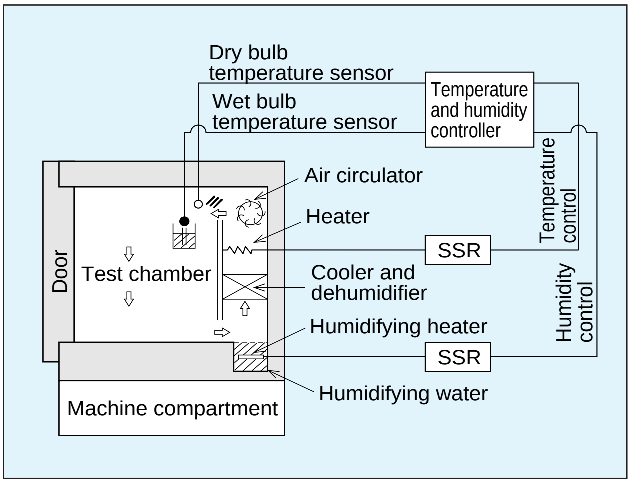


Fig. 3 One type of temperature and humidity chamber

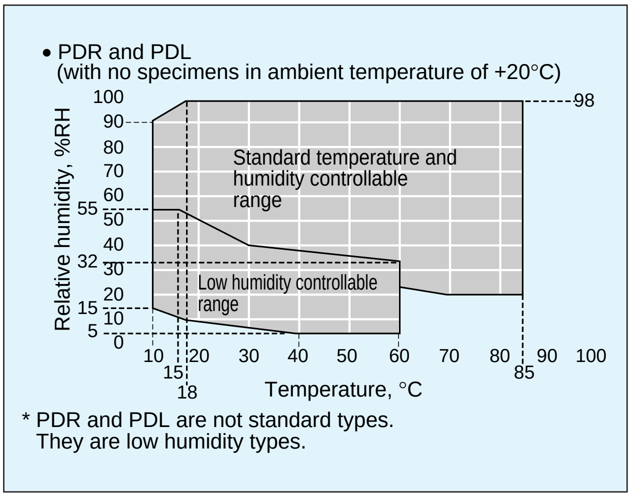


Fig. 4 Example of the temperature and humidity control range in temperature and humidity chambers

The range in which temperature and humidity can be controlled simultaneously is from 10°C at 15% RH to 85°C at 98% RH. The range of operation for temperature alone depends on the machine type, but in general extends from –70°C to +150°C. Therefore, in psychrometers for measurement control, wet- and dry-bulb thermometers and hygrometers have been used from the outset. Even today, a better means of measuring temperature and humidity has still not been devised.

Some companies, foreign companies in particular, are using lithium chloride dew-point hygrometers and chilled mirror dew-point hygrometers for measurement control.[9), 10)]

Also, so-called electronic humidity sensors can be used if the temperature and humidity conditions and the usage atmosphere are limited, but the writers of this report do not believe that such devices provide a requisite level of reliability to make it possible to mount them as standard equipment on the Platinous Series. For example, even at normal temperature and humidity the humidity sensor could fail due to the effect of volatile matter unexpectedly coming from the specimen, so this presents a major risk for use as standard equipment.

Actually, a humidity sensor can be mounted as an option in the walk-in type H-Series temperature and humidity chambers, because the humidity sensor is easier to use for control in the low-temperature and low-humidity region of 5°C and 5 percent relative humidity. Also, in the environmental chamber used for analyzing the physiology and ecology of the human body, use of a humidity sensor is now standard. Even in the temperature and humidity chamber, the conditions of user applications must be fully considered for selecting optional mounting technology.

Next, let’s look at psychrometers.

3. The psychrometer as a weather gauge

3-1 Construction of the psychrometer

The psychrometer has been used for over 100 years as a weather gauge. The Assmann psychrometer, designed in 1887 by R. Assmann, is a typical psychrometer. Fig. 5 shows an external diagram of this type of psychrometer.

Two identical glass thermometers are placed inside a metal ventilation tube that protects from surrounding radiation, and a fan is used to circulate the surrounding air over the thermometers. A gauze wick covers the temperature-sensing area of one thermometer, and this wick is dampened with water for taking measurements. The thermometer covered with the wick is called a wet-bulb thermometer, and its temperature-sensing area is called a wet bulb. The other thermometer is a dry-bulb thermometer, and its temperature-sensing area is called a dry bulb.

Even today the basic construction of this type of psychrometer has not changed, with only the spring-wound ventilation fan having been changed to a motor-driven type. Depending on the type of equipment, a wick and water pot are devised that can be used for electrical output from the thermometer.

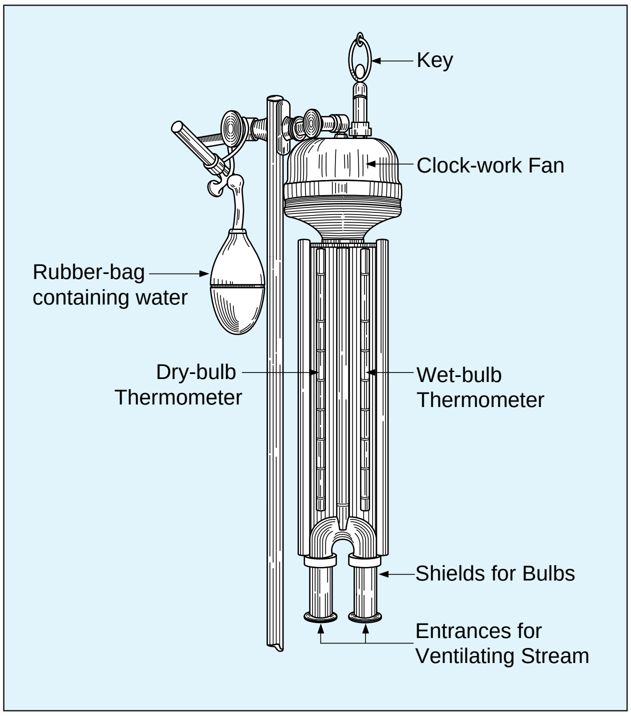


Fig. 5 Assmann psychrometer

3-2 Principle of the psychrometer

In the psychrometer, moisture evaporates from the wet bulb in response to the dryness of the surrounding air and the temperature displayed on the wet-bulb thermometer drops and reaches the equilibrium temperature, which is the temperature displayed on the wet-bulb thermometer. The corresponding air temperature is called the dry-bulb temperature.

According to the boundary-layer theory, evaporation from the water surface can be shown approximately with the following formula. When this is applied to the evaporation of water in the wet bulb, it becomes:

$$Ga = Dp\,(e_{sw} - e)\,/\delta \quad (1)$$

Where:

Ga = the flow mass per unit of surface area of evaporating water vapor,

Dp = the pressure-base diffusion constant,

e_{sw} = water vapor pressure in contact with the surface of the water (i.e., saturation water vapor pressure in wet bulb temperature),

e = water vapor pressure in areas well away from the surface of the water

(i.e., water vapor pressure in the desired atmosphere), and

δ = the thickness of the boundary layer.

The value of δ, the thickness of the boundary layer, varies according to wind speed. Therefore, the formula for ϕ, the quantity of heat cooled by water evaporation, is as follows.

$$\phi = Ga \cdot L_H \quad (2)$$

Where:

ϕ = the quantity of heat cooled by water evaporation,

Ga = flow mass per unit of surface area of evaporating water vapor, and

L_H = evaporation latent heat of the water

The quantity of heat cooled by this evaporation matches the quantity of heat transmitted to the wet bulb from the surrounding area, providing balance. Items such as the following can be given as sources of the quantity of heat transmitted from the surrounding area.

- Heat transmitted from the air
- Radiated heat
- Heat transmitted from the thermometer
- Heat transmitted from the supply water

We have presented above a very approximate outline. For a detail theoretical analysis of the psychrometer, please refer to the books and literature in the references. 13), 14), 15)

3-3 Formulas for psychrometers

The psychrometer does not give humidity as an absolute value, but rather gives the wet- and dry-bulb temperatures from which wet- and dry-bulb formulas can be used to find the partial water vapor pressure in the air.

The following Sprung formula is very widely used as a formula for psychrometers. Sprung came up with it in 1888 using the Assmann psychrometer.[16)]

$$f = f' - A\,(t - t')\,b/755 \qquad (3)$$

Where:

t = dry-bulb temperature
t' = wet-bulb temperature
f = water vapor pressure in the air to be obtained
f' = saturated water vapor pressure in wet-bulb temperature t'
b = atmospheric pressure
A = the psychrometer constant

Sprung used the following two values of standard humidity to perform experiments to determine constant A.

[1] Dew point found using an ether-cooled dew-point gauge
[2] Gravimetric method causing absorption of water vapor in a U-shaped tube filled with phosphates

Table 1 shows the results of those experiments

Table 1 Results of Sprung's experiment

*	*	b	t	t'	f'	f		f'—f		t—t'	A	
						durch Absorp.	durch Taup.	durch Absorp.	durch Taup.		durch Absorp.	durch Taup.
		mm	°C.	°C.	mm	mm	mm	mm	mm	°C.	mm	mm
1887	27. XI	757	16.6	11.0	9.7		6.6		3.1	5.6		0.55
	28. XI	760	21.1	12.9	11.1		6.8		4.3	8.2		0.52
	do.	760	21.2	12.9	11.1		7.3		3.8	8.3		0.46
	1. XII	764	21.3	12.5	10.8		6.7		4.1	8.8		0.46
1888	11. II	748	18.9	11.9	10.4	6.8	6.5	3.6	3.9	7.0	0.52	0.56
	18. II	746	8.6	6.2	7.1		5.7		1.4	2.6		0.54
	21. II	754	8.3	5.3	6.6	5.2	5.0	1.4	1.6	3.0	0.47	0.53
	25. II	762	7.6	4.6	6.3	4.9	4.8	1.4	1.5	3.0	0.47	0.50
	29. II	767	7.5	4.0	6.1	4.3	4.4	1.8	1.7	3.5	0.51	0.48
	6. III	757	16.3	8.6	8.3	4.3	4.5	4.0	3.8	7.7	0.52	0.49
										Mittel:	0.498	0.509

* Date of experiment

Measurements were made 10 times using the dew-point method in [1] and five times using the gravimetric method in [2]. A varied from 0.46 to 0.56. A = 0.5 was used as an average.

At JIS, Sprung's formula was transcribed in the following way, and is used as a standard.

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

Where:

A = 0.000662 (when the wet bulb is not frozen)
A = 0.000583 (when the wet bulb is frozen)

The symbols in formula (3) can be replaced with f = e, f' = e_{sw}, b = p, and t' = t_w. A becomes 0.5/755 = 0.000662, and is the same number. Nothing is written in the reference literature[16)] about when the wet bulb is frozen.

Saturated water vapor pressure e_s, at dry bulb temperature t, is found using the formula (or table) for saturated water vapor pressure.

The formula for relative humidity U (%) is thus:

$$U = (e/e_s) \times 100 \qquad (5)$$

A number of formulas besides the Sprung formula are used as formulas for psychrometers, which is explained in the JIS[17)] commentary. All formulas used are based on the fundamental characteristic of having the temperature differential between the wet- and dry-bulb temperatures $(t - t_w)$ proportional to the water vapor pressure differential $(e_{sw} - e)$. Also, the psychrometer theoretically is affected by the wind speed. The Assmann psychrometer requires a wind speed of from 2 to 5 meters per second.

4. The psychrometer in environmental testing equipment

4-1 The structure of the psychrometer

The basic structure of environmental testing equipment (the temperature and humidity chamber), as shown in Fig. 3, consists of an arrangement for regulating the temperature and humidity of air, which is then circulated from the air-conditioner to a hermetically sealed, comparatively narrow test area. Most wet- and dry-bulb thermometers are mounted near the port for the air to enter the chamber from the air conditioner. Feedback control is employed to maintain the temperature and humidity settings inside the chamber.

Because of this, ventilation tubes, such as those on the Assmann psychrometers, are not used. There are many types of environmental testing equipment, so the structure of the psychrometer will depend on the manufacturer, and will even be different on different types of equipment built by the same manufacturer. Differences are particularly seen in wind direction, wick shape, and supply water mechanisms, and even intellectual property rights may be involved. Fig.6 shows typical constructions that are presented in JIS[17)] commentary. Of the three examples shown in Fig. 6, the one on the left corresponds to one type of construction used at Tabai Espec. The examples in the center and on the right are used by other companies.

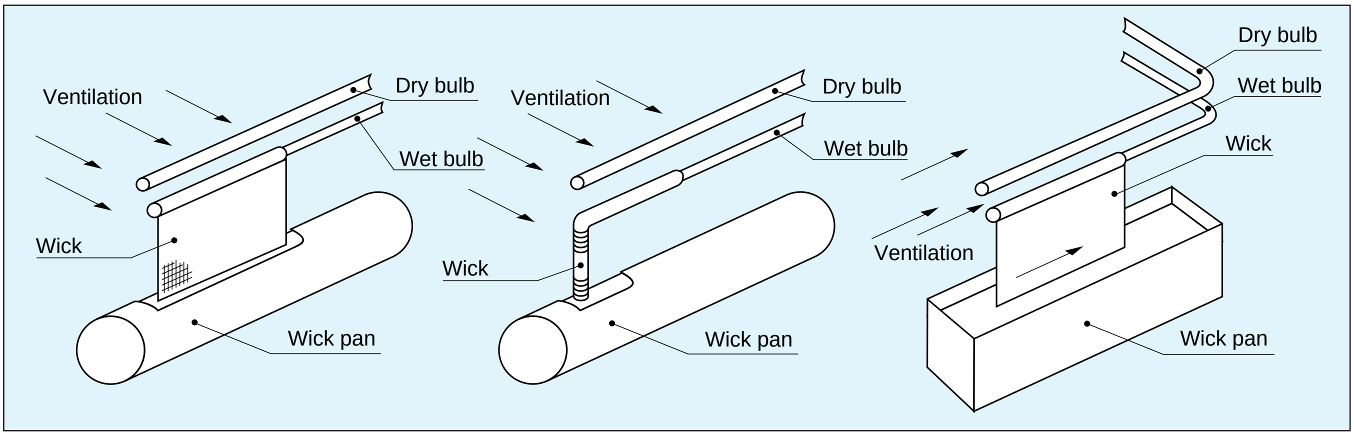


Fig. 6 Typical psychrometers used in environmental testing equipment

4-2 Formulas for psychrometers

When the wind speed is at least 2.5 m/s, the JTM standards use the Sprung formula as the formula for the psychrometer used to evaluate performance of the temperature and humidity chamber. When a wind speed of at least 2.5 m/s cannot be maintained, the Pernter formula is used. The Pernter formula and its constants are as follows.

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

Table 2 Pernter formula constants

Wind speed around the wet bulb	When the wet bulb is not frozen		When the wet bulb is frozen	
	a	b	a	b
0 – 0.5	0.0012	610	0.00106	689
1.0 – 1.5	0.0008	610	0.000706	689
Min.2.5	0.000656	610	0.000579	689

The JTM standards do not prescribe anything about the psychrometer used to measure and control the equipment. In actual practice, the Sprung formula and the Pernter formula are used without modification for the psychrometers used in the equipment.

The JIS[17)] commentary concerning the psychrometers used for the equipment states, “Formulas for psychrometers suited to the conditions of usage and to specifications such as the relationship between the wind speed and the direction of the wind current vis-a-vis the wet bulb must be scrutinized and clarified.” Strictly speaking, the optimum formula exists for the specific construction of the psychrometer.

However, the authors of this report believe that in environmental testing equipment, scrutinizing the formula itself in regard to usage conditions is not very practical. The four major reasons are as follows.

(1) In environmental testing equipment, many different types of equipment construction are used depending on the aims and applications of the test, and the construction of the psychrometer mounted on the equipment will vary. Scrutinizing the formula for psychrometers itself in regard to usage conditions for each machine type is not practical. It would be better to unify the formulas in one all-purpose formula.

(2) With ventilated psychrometers, even in the widely-used Sprung formula the value of the constant A is not uniform in the standards of all countries. In the ISO[18)] and the ANSI/ASHRAE[19)] the value is 6.5 to 6.9×10^{-4}, while in ASTM[20)], the value is 6.2 to 6.9 $\times 10^{-4}$.

(3) The life of the wick is crucial to the performance of the psychrometer mounted on environmental testing equipment. Required environmental testing cannot be carried out with a wick that has a short life, so both life and precision must be considered in the construction.

(4) Important points for gauges include resistance to being affected by error-producing factors, minimal dispersion, and ability to maintain stable measurement. Furthermore, since the measurement values are used to control the equipment, performance in controlling the equipment and responsiveness must be considered together.

5. Error-producing factors in humidity measurement

5-1 Saturated water vapor pressure

Various units and indication methods are used for humidity, and they must be converted. The basis for calculating humidity is the saturated water vapor pressure formula (or the table). The JTM standards refer to JIS[17)]. The formula used is the Sonntag formula, based on the International Temperature Scale-90. Before the revised edition (JTM K 01[–1985, 1991]), the Goff-Gratch formula was followed according to the pre-revision JIS[21)].

Fig. 7 shows a saturated water vapor pressure line and constant relative humidity line.

Vapor pressure increases exponentially in response to temperature. Therefore, temperature measurement errors in the high and low temperature regions will cause large errors in humidity measurement. Also, even at any one temperature, the size of the error will differ in high and low humidity regions. The following section, 5-2, shows specific values.

Looking at the psychrometric chart, always given in air conditioning handbooks, gives a good understanding of the matter.

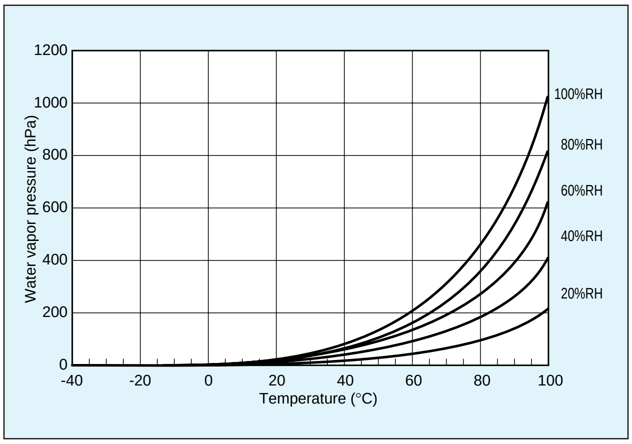


Fig. 7 Constant relative humidity line graph and water vapor pressure

5-2 Temperature

The psychrometer can theoretically provide accurate humidity levels if the wet- and dry-bulb temperature differential ($t - t_w$) is accurate. Even a 0.1°C error in the same direction in both dry-bulb temperature t and wet-bulb temperature t_w, will have little effect on the relative humidity. Table 3 shows the effect of errors in measuring the wet- and dry-bulb temperature differential.

Table 3 Level of relative humidity error due to errors in the wet- and dry-bulb temperature differential

■ 85°C 85%RH

Units: %RH

		Dry bulb temperature t (°C)		
		84.9	85.0	85.1
Wet bulb temperature t_w (°C)	81.1	85.6	85.2	84.9
	81.0	85.2	84.9	84.5
	80.9	84.9	84.5	84.2

■ 10°C 95%RH

Units: %RH

		Dry bulb temperature t (°C)		
		9.9	10.0	10.1
Wet bulb temperature t_w (°C)	9.7	97.6	96.4	95.2
	9.6	96.4	95.2	94.0
	9.5	95.1	94.0	92.8

■ 10°C 5%RH

Units: %RH

		Dry bulb temperature t (°C)		
		9.9	10.0	10.1
Wet bulb temperature t_w (°C)	1.2	6.7	6.2	5.6
	1.1	5.8	5.2	4.6
	1.0	4.9	4.3	3.7

Because of this, with the psychrometer, rather than independently measuring the dry bulb temperature and the wet bulb temperature and accumulating error dispersion for each temperature measurement, it would be better to measure accurately the differential between the dry bulb temperature and the wet- and dry-bulb temperature.

5-3 Atmospheric pressure

As seen in formula (4) and formula (6), the formulas for the psychrometer include the atmospheric pressure. The impact on relative humidity can be ignored if the variation is in the range of 1 to 2 percent from standard atmospheric pressure. However, when the variation reaches 3 percent, the differential in the low-temperature, low-humidity region cannot be ignored. Table 4 shows an example of calculating relative humidity at the standard atmospheric pressure of 1013hPa, and at the low atmospheric pressure of 980hPa. Normally, when atmospheric pressure is given as meteorological information it has first undergone sea-level correction (e.g., reference[22]), so the value must be thought of as the atmospheric pressure for the altitude of that location.

Table 4 Variations in relative humidity due to variations in atmospheric pressure

Units: %RH

Dry bulb temperature t (°C)	Wet bulb temperature t_w (°C)	Standard atmospheric pressure 1013hPa	Low atmospheric pressure 980hPa
10.0	9.6	95.2	95.2
	5.6	50.0	50.8
	1.1	5.2	6.8
30.0	29.3	94.9	95.0
	22.1	50.2	50.6
	12.1	4.9	5.9
50.0	49.1	95.1	95.1
	38.8	50.0	50.2
	21.3	4.9	5.4

5-4 Wind speed

The psychrometer is theoretically influenced by wind speed. Experiments[23] have shown the dependence of wind speed in the psychrometer constant A in Sprung's formula. According to the experiments:

$$A = 9.90 \times 10^{-4} \left(\frac{1+0.69\sqrt{V}}{1+1.35\sqrt{V}} \right) \qquad (7)$$

V: wind speed (m/s)

When V = 1.5 (m/s), $A = 6.9 \times 10^{-4}$. When V = 2.5, $A = 6.6 \times 10^{-4}$. When V = 5.5, $A = 6.2 \times 10^{-4}$. The JIS[17] commentary presents detailed calculations of the differences in relative humidity due to differences in constant A. In the low-temperature, low-humidity regions, the difference is greater than ±1 percent relative humidity.

Pernter's formula conveniently can be used even at low wind speed, but at 0 to 0.5 m/s, it becomes the same as the simple unventilated psychrometer, and precision suffers. Therefore, JTM K 01:1998 states that when using the psychrometer at low wind speed, calibration is desirable according to a higher level humidity gauge. A higher level humidity gauge corresponds to a traceability system, based on the Japanese measurement law. Specifically, this means a chilled mirror surface dew-point hygrometer with an automatic equilibrium function built in.

As seen in Fig. 3, most psychrometers for measurement control in environmental testing equipment are installed near the port where the wind enters the chamber from the air conditioning unit, and a minimum 2.5 m/s wind speed is maintained. Therefore, when desiring to lower the wind speed so that the wind doesn't hit the specimens, special countermeasures must be taken such as using a chamber within specially designed precision, or the wind may be directed at the entire surface of the ceiling of the temperature and humidity chamber.

5-5 Wet bulb water and wick

The purity of the water supplied to the wet bulb is a vital factor. Tap water or other impure water causes measurement error of the wet bulb temperature, and impurities in the wick shorten the promoted life[24]. Also, the life of the wick varies according to the temperature and humidity region of use. At Tabai Espec, we encourage the use of pure water with maximum conductivity of 10μ S/cm. As a rule of thumb, the wick should be changed once a month.

The wick covering the wet-bulb thermometer should be of a length that isn't affected by heat conducted from the thermometer, and requires a certain amount of length. The shape of the wick and the materials used are known to be intimately related to the life of the wick. At Tabai Espec, other than the long (flag-shaped) wick shown in Fig.6, we also use a long wick with three sides of a square cut into it (the left side not cut). This wick shape is called a self-cleaning wick, and the water that is wicked up very gradually naturally flows away. Because the water is constantly flowing, impurities do not tend to accumulate, and the wick has a particularly good life in high-temperature, low-humidity regions with a large amount of moisture evaporation[25].

6. In conclusion

As hygrometers for environmental testing equipment, electronic humidity sensors and other types of humidity gauges are not likely to completely replace psychrometers any time soon. The psychrometer combines simple construction and high reliability. However, at low-temperature, low-humidity regions, precision is theoretically lower, so some equipment types have humidity sensors installed. In some cases, equipment performance indication is classified as being different in low-temperature, low-humidity regions. The psychrometer still has a lot of room for improvement in wick life and in maintenance, but the question of whether it will be replaced by another type of hygrometer depends on the combination of cost, precision, and reliability.

In the final analysis, equipment performance will be evaluated by the user who is actually performing the environmental testing. At Tabai Espec, we are doing everything in our power to provide products that meet user needs.

[Bibliography]

1) JTM K 01–1985, 1991, "Standard for performance of humidity chambers".
2) JTM K 03–1988, 1992, "Standard for performance of environmental temperature and humidity rooms".
3) "Investigative report on standardizing temperature and humidity chambers in 1981", Japan Testing Machinery Association, (1982).
4) "Investigative report on standardizing temperature and humidity chambers in 1982", Japan Testing Machinery Association, (1983).
5) "Investigative report on standardizing temperature and humidity chambers in 1986", Japan Testing Machinery Association, (1987).
6) BS3718, "Specification for Laboratory humidity ovens (non-injection type)", (1964).
7) BS3898, "Specification for Laboratory humidity ovens (injection type)", (1965).
8) BS4864, "Recommendations on the design and testing of enclosures for environmental testing", (1973).
9) "Investigative report on standardizing temperature and humidity chambers in 1994", Japan Testing Machinery Association, (1995).
10) "Investigative report on standardizing temperature and humidity chambers in 1995", Japan Testing Machinery Association, (1996).
11) JTM K 01–1998, "Humidity chambers-Test and indication method for performance".
12) R.Glazebrook, "A Dictionary of Applied Physics", Vol.lll,425, Macmillan and Co., London, (1923).
13) Kamekichi Shiba, "Anthology of articles on measurement engineering", Kogyogijyutsusha, (1975).
14) "Humidity and moisture measurement and environmental monitoring." Japan Society of Mechanical Engineers, Gihodo, (1992).
15) R.G.Wylie and T.Lalas, "The WMO Reference Psychrometer", CSIRO, Australia, (1981).
16) A.Sprung, "Uber die Bestimmung der Luftfeuchtigkeit mit Hilfe des Assmannschen Aspirationspsychrometers", Z.Angew.Merteorol, Das Weter, 5, 105-108, (1888).
17) JIS Z 8806 –1995, "Humidity-Measurement methods".
18) ISO 4677/1-1985(E), "Atmospheres for conditioning and testing-Determination of relative humidity-Aspirated pychrometer method.
19) ANSI/ASHRAE 41.6-1994 (Supersedes ANSI/ASHRAE 41.6-1982), "Method for Measurement of Moist Air Properties".
20) ASTM E337-84(Reapproved 1990), "Standard Test Method for Measuring Humidity with a Psycrometer (the Measurement of Wet-and Dry-Bulb Temperatures)".
21) JIS Z 8806 –1981 (1986), "Humidity Mesurement methods".
22) "Average annual atmospheric pressure for each month, 196", Rika nenpyo(chronological Scientific Tables), Maruzen Co.,Ltd., (1996).
23) Yoshikazu Yamamoto, Tyutomu Yamamoto, "The affect of wind speed on the psychrometer constant.", Journal of the Meteorological Society of Japan, special ed., Vol.2, No.26, 54-58, (1948).
24) Akihiko Awano, Shigemi Suzuki, "Reliability of wet-bulb wicks for humidity testing", Reliability Engineering Research, Vol.75, No.76, The Institute of Electronics, Information and Communication Engineers, (1975).
25) "Wet-bulb wicks in psychrometers", Japanese Utility Publication No.16676 of 1987.

Topics

Coping with environmental preservation in the Platinous K Series

Kensuke Akamatu*

Current newspapers are replete with articles on preserving the global environment. In December 1997, the Third International Conference on Pollution (COP3) was held in Kyoto, and a resolution was adopted determining specific actions and countermeasures necessary to achieve targets for carbon dioxide reduction. At Tabai Espec as well, as an initial step for coping with that problem, we have obtained the Environmental Management System certification (ISO 14001) of the International Standardization Organization (ISO). As one specific activity in that regard, we have introduced the Platinous K Series of temperature and humidity chambers, which are now our main products for dealing with environmental preservation. This product line went on sale on August 1, 1997.

Photo 1 The Platinous K Series

1. Introduction

Problems have materialized in relation to "preservation of the global environment", such as destruction of the ozone layer, global warming, and acid rain. It is becoming ever more crucial to fully consider these problems at the stage of product development.

In 1992, we replaced the special freon in our Platinous S Series with alternative freon (HCFC) in our efforts to protect the ozone layer, but based on our company environmental management policy, we have developed the current K Series from the planning stage to cope with environmental protection in regard to (1) preventing global warming, (2) changing over to alternative freon (HFC), and (3) incorporated such environmental preservation measures such as measures for recycling.

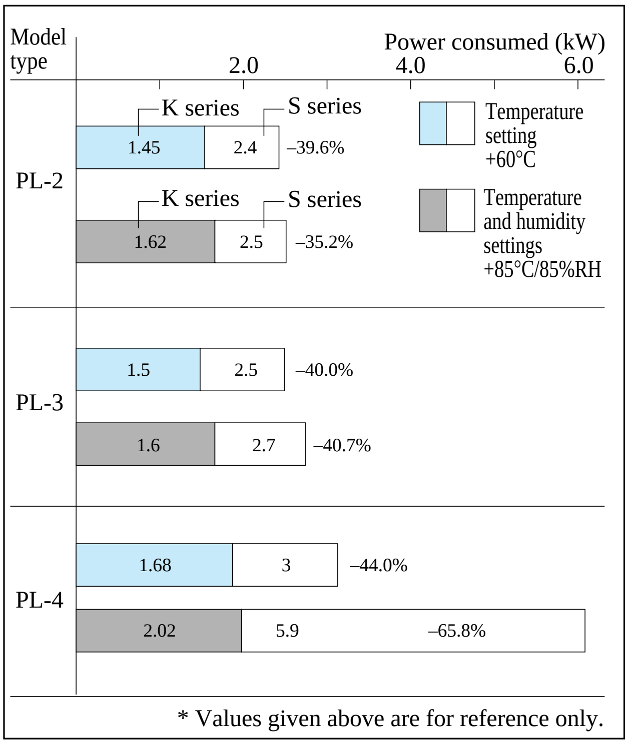
*Technical Center

2. Preventing global warming (energy conservation)

We have set a target of reducing product energy consumption by at least 30 percent as a measure for preventing global warming. With the K Series, we have reduced energy consumption in the following ways.

In the past, a balanced temperature and humidity control method has been used to improve temperature and humidity control in the Tabai Espec temperature and humidity chambers. A cooling unit (also used as a dehumidifier) with a large thermal capacity was continuously operated at a fixed capacity, while a small thermal capacity heater and humidifier were continuously controlled with a temperature and humidity regulator, balancing the overall temperature and humidity, and precisely creating the desired temperature and humidity rapidly.

Table 1 Comparative energy consumption of the Platinous K Series vs. the S Series



All products in this line-up since the 1989 Platinous F Series have used an electronic expansion valve to vary the capacity of the large thermal capacity cooling unit (also used as a dehumidifier), and the refrigeration capacity (dehumidifying capacity) was reduced to achieve balance at the minimum capacity not affected by ambient temperature or disturbance, thus promoting energy conservation. However, with this method, the balance point could not be lower than the level set from the low pressure usage limit of the compressor.

With the new K Series, at a minimum temperature of 0°C, using a bypass circuit when operating temperature and humidity, refrigeration capacity can be dropped without going below the low pressure, attaining further energy reduction. In addition, the refrigerator unit COP (results coefficient) has been improved by using a larger condenser and by increasing the condenser fan capacity. Furthermore, a refrigeration control algorithm has been developed yielding more precise control.

The PL-2, 3, and 4 types with the bypass circuit mounted have achieved a 30 percent reduction in energy usage, and other models have achieved a 15 percent reduction.

3. Changing to alternative freon (HFC)

The regulations from the Meeting of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer limited the use of current HCFC refrigerants to no more than the quantities used in 1989. However, calls for stronger regulations led especially by the Europeans resulted in the development of systems using R404A (high temperature refrigerants, with a type good to –40°C and a type good to –70°C) and R508A (low temperature refrigerant good to –70°C) with an ozone depletion potential of zero in the K Series.

However, these alternative refrigerants suffer from the defect of a large global warming coefficient. Even with an ozone layer depletion potential of zero, equipment that has higher power consumption in addition to a greater output of CO_2 is connected to global warming. Currently, the TEWI* evaluation index is being advocated as an index for overall judgement of such contradictory influences.

At Tabai Espec, we hermetically seal refrigerants with completely welded joints for the refrigeration circuits. Also, we thoroughly control refrigerant discharge at the production stage. Therefore, if refrigerants are properly recovered during maintenance and at disposal, the impact of the refrigerants on global warming and on destruction of the ozone layer will be held to a minimum.

As was explained in the previous section, we have attained a 15 to 30 percent reduction in energy consumption compared to previous equipment.

Table 2 Refrigerant characteristics

Substance	Chemical formula	Ozone layer depletion potentials	Global warming coefficient
HCFC22	$CHC1F_2$	0.055	1700
HFC134a	CF_3 CH_2 F	0	1300
R404A	HFC125/HFC143a/HFC134a	0	3750
HFC23	CHF_3	0	11700
R508A	HFC23/FC116	0	12300
CFC12	$CC1_2$ F_2	0.9	8500
R502	R22/R115	0.180	5590

Alternative refrigerant evaluation program technology committee (December 7, 1995)

For the above reasons, we believe that overall the newly developed Platinous K Series are products that respond to the problems of both global warming and the destruction of the ozone layer.

4. Promoting Recycling

To promote recycling of raw materials, we are using resin plastic molded products and die cast materials marking, making it easy to sort the materials at disassembly so they can easily be reused.

5. Summary

The newly developed Platinous K Series are the first products developed by Tabai Espec since we acquired ISO 14001 certification, and the products have been developed with full-scale environmental preservation considerations built in from the design stage onward. There are many more areas in which we must technologically meet the challenges, but at this point we have met our targets for handling the initially planned environmental preservation in regard to energy conservation and the use of freon gas.

For future product development, consideration for the environment is indispensable, and we believe demands for such consideration will become much stronger. We recognize that environmental preservation is a crucial topic for the whole world, and we intend to continue developing products that are more gentle on the environment.

Tabai Espec's Platinous K Series has been awarded the "Commendation for Excellence in Energy-Efficient Equipment"

The Platinous K Series has been selected by the Japan Machinery Federation for excellence in energy-efficient equipment, and has been presented with the "Japan Machinery Federation Presidential Prize (Energy Conservation Division)".

Three models of the Platinous K Series low-temperature and humidity chambers have been honored with the award.

The commendation system for excellence in energy-efficient equipment was established to recognize corporations or corporate groups for contributing to the promotion of the efficient use of energy by developing equipment with superior energy-conserving features and working to provide a practical application. The award aims to popularize superior energy-efficient equipment and to promote the development of such equipment. This commendation has been awarded annually since 1980, and eleven equipment models were honored with the award in 1998.

At Tabai Espec, we shall continue to strive to meet the challenges of environmental preservation by creating products with energy-efficient technology, and keeping our customers satisfied.

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*TEWI stands for Total Equivalent Warming Impact, which is the index for evaluating the impact of greenhouse gases on global warming.
This index is used by such agencies as the International Council on Air Conditioning and Refrigeration Manufacturer's Association (ICARMA).
TEWI = (the equivalent amount of CO_2 directly emitted) + (the equivalent amount of CO_2 indirectly emitted)

- The equivalent amount of CO_2 directly emitted ($kgCO_2$) =
  (the amount of coolant leakage occurring during machinery operation and in disposal) × GWP
- The equivalent amount of CO_2 indirectly emitted ($kgCO_2$) =
  (annual energy consumption) × (operating times per year) × (CO_2 conversion) × (the amount of CO_2 produced during power generation)

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