

Understanding the Technology 1

Reliability assurance and reliability testing (environmental testing)
- Why defects and failure occur, and the significance of environmental testing -

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I was recently given the opportunity to analyze the root cause of defects and failure^{1),2),3),4)} related to reliability and quality control. Why do defects and failure occur? Ultimately, if we answer in terms of reliability and quality control, failure stems from a lack of process capability and a lack of design margin. In this report, I shall deal with preventing defects and failure, and I shall consider the use of reliability testing--environmental testing in particular--as a means of reliability assurance.

I would like to see a redefinition of reliability related to defects and failure in the field of reliability technology, and with research and investigation performed as reliability technology. Rather than technology-based, this approach⁵⁾ is based on reliability and quality control administrative technology performed during product development and manufacturing. Reliability testing--environmental testing in particular--is widely employed as a means of reliability assurance, but such testing does not fully detect all defects and failure. However, by varying environmental stress and by increasing its severity, we can indirectly exaggerate the intrinsic stress failure mechanisms and induce failure. This serves as a crucial means of reliability assurance. Because environmental testing increases the severity of environmental stress to investigate the stability of product functions, environmental testing is known as reliability testing.

1. Introduction

Nowadays, there is some anxiety about reliability and quality control for Japanese traditional technology. I recently was engaged in the business of supplying manufacturing technology for liquid crystal displays (LCDs) to Taiwan, for which I created a reliability and quality control system. There I was given the opportunity to analyze the root causes of defects and failure^{1),2),3),4)} related to reliability and quality control. This experience caused me to consider the essential matters of reliability and quality control; namely, with all this reliability assurance activity, why should defects and failure occur at all and what could be done to prevent them?

Ultimately, to answer the question of why failure should occur in terms of reliability and quality control, failure stems from a lack of process capability and a lack of design margin. I would like to see a redefinition of reliability related to defects and failure in the field of reliability technology, and with research and investigation performed as reliability technology. Rather than technology-based, this approach⁵⁾ is based on reliability and quality control administrative technology performed during product development and manufacturing.

Reliability testing--environmental testing in particular--is widely employed as a means of reliability assurance, but such testing does not fully detect all defects and failure. However, by varying environmental stress and by increasing its severity, we can indirectly exaggerate the intrinsic stress failure mechanisms and induce failure. This serves as a crucial means of reliability assurance. Because environmental testing increases the level of environmental stress to investigate the stability of product functions, environmental testing is known as reliability testing.

2. Development and manufacturing processes: from customer demand to meeting customer needs

I would like to use Fig.1, which takes the printer as an example that includes both development and manufacturing, to explain the process from customer demand to meeting customer needs. Based on this explanation, I would like to redefine both "failure" and "reliability."

In this example, the customer wants to use the printer to print out some New Year's greeting cards. This chart shows the development and manufacture of a printer for that purpose. Developing function specifications based on customer demand is known as product "planning," and following that, developing the technical (design) specifications is known as "design." Process design is referred to as developing the technical (design) specifications based on the 4 M's of manufacturing (man, machine, material, and method). Manufacturing is the process of creating a product using those 4 M's. The functions of the product are realized through the activity using the product. In this case, that means the activity of printing.

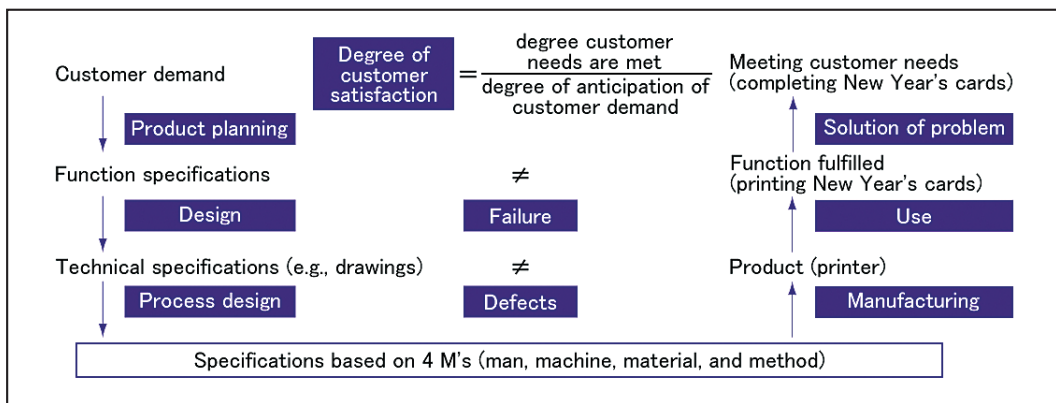


Fig.1 The relationship of development and manufacturing to defects, failure, and customer satisfaction

Using Fig.1, I would also like to explain defects, failure, and customer satisfaction. Defects can be seen as items that do not meet the technical specifications as represented by the drawing of the final product. Failure can be seen as a product function that does not execute in accord with the function specifications. The degree of customer satisfaction is the degree to which the product fulfills the need as anticipated by the customer's New Year's greeting card demand. The customer is not looking for a specific printer. He wants to print his New Year's cards in the manner he desires.

3. Why does failure occur?

When we consider the question of why failure occurs, it is natural to say that defects cause failure, but since failure can occur even without defects, I would like to consider this latter type of failure not caused by defects.

3-1 Development breeds new failure mechanisms

Development normally consists of creating a completely new design. Changes in design lead to changes in the operating principle. From the standpoint of reliability, this means that we have created new failure mechanisms. Naturally, understanding this fact does not make it any easier to ascertain the sources of the new problems.

3-2 Degradation and changes over time

Confirming the initial reliability (at time zero) is much easier than confirming the reliability after a product has experienced degradation and changes over time. Differences in characteristic values after a product undergoes changes over time are caused by usage conditions, environmental conditions, and elapsed time. The impact of elapsed time stems from both calendar time and usage time.

3-3 Reliability testing

In accelerated life testing, only presumed failure mechanisms are accelerated. It would not be possible to accelerate all failure mechanisms. Therefore, in accelerated life testing of specified failure mechanisms, new failure mechanisms require new test methods. To the extent that new failure mechanisms are not specified, it will be impossible to discover new failure mechanisms.

3-4 Actual conditions used

There are a great many actual conditions used corresponding to the presumed differences at each stage of development. Usage conditions and environmental conditions are combined on the chance that the combined conditions can lead to failure.

4. Why do defects occur?

Defects are generated by deviations from the control conditions of the 4 M's of manufacturing (man, machine, material, method). Let's look at deviations from these 4 M's.

4-1 Man

With manpower there is a trade-off between quality work and cheap labor costs. For example, there has been a recent trend to transfer manufacturing jobs to China. When products are manufactured abroad, new "man" problems crop up that did not exist in Japan, such as problems with language. There are innumerable quality control issues related to "man," such as manual dexterity, problems with morale, and human relations.

4-2 Machine

Development includes the aspect of transferring control to technological manufacturing. A developmental prototype "machine" and a manufacturing prototype "machine" quite properly have fundamental differences. Therefore, defects can stem from the differences in the two. Furthermore, when we enter the stages of manufacturing and mass production, "machine" degradation causes defects in products manufactured by that machine. The degradation of such devices as molds and dies limits the total volume of production.

When speaking of "machines," let us note that mechanizing work refers to work performed by man. Mechanizing work that cannot be performed by man leads only to the production of defects. First, a person tries to do something. If he succeeds, then the work can be mechanized.

4-3 Material

"Material" is just like "machine" in that material for developmental prototypes and material for manufacturing prototypes quite properly have fundamental differences. Therefore, defects can stem from the differences in the two. Furthermore, if we produce a large volume at the production and mass production stage, defects will appear that did not show up during prototype production.

4-4 Method

"Method" is generally based on probability using samples during prototype development. When we reach the stages of production and mass production, changes occur in man, machine, and material, and if method cannot keep pace with these changes, defects will occur.

5. Preventing defects: Cp, Cpk, and Cpm

The process capability indexes Cp, Cpk, and Cpm:

$$Cp = (Su - Sl) / 6 \quad (\text{formula 1})$$

$$Cpk = (1 - k) Cp \quad (\text{formula 2})$$

$$Cpm = (Su - Sl) / 6 \quad * \quad (\text{formula 3})$$

Where,

Su = upper margin specifications

Sl = lower margin specifications

= standard deviation

$$K = \frac{|(Su + Sl) / 2 - \mu|}{(Su - Sl) / 2}$$

* = The square root of the product of dividing the sum of the squares of deviations by sample size "n".

Cpk represents values that fall outside of specified values, while Cpm represents values that fall outside of target values. To put it briefly, specified values serve as a contract between the designer and the manufacturer, and determine the margins between acceptable products and defective products. Cpk can serve to present the ratio of defects, but if, for example, a customer lodges a complaint, that case falls into a separate category. The customer requires basic functionality, and so that example can be evaluated with Cpm.

The LCD device has specified color standards. Target values, white for example, determine what value should represent that specified color. For convenience, there is an upper margin and a lower margin to the specifications, but these upper and lower margins are set by the designer based on current technology. Cpk has meaning from the standpoint of defects, but Cpm can be used to evaluate what is closest to the target value. Therefore, Cpk should be used in evaluations to reduce defects, while Cpm should be used in evaluations to reduce customer complaints.

6. Combining process capability and design margin to prevent failure

The question of why failure occurs can be answered in terms of reliability and quality control by saying that failure stems from a lack of process capability and a lack of design margin. Let's look at a specific example. The stress-strength model is a typical model for predicting reliability. Fig.2 uses a box and whiskers plot to show the relationship between stress and strength.

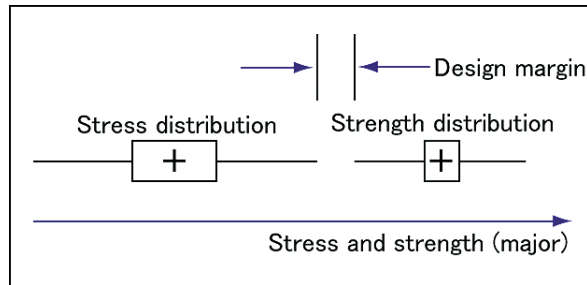


Fig.2 Stress-strength model

When stress, a load (L) for example, becomes greater than the supporting hardness and tensile strength (S), the stress will break the supporting object. When L and S respectively comply with normal distribution, the failure probability P(f) becomes as shown in formula 4.

$$P(f) = P(S < L) = P(N_s(\mu_s, \sigma_s) < N_L(\mu_L, \sigma_L))$$

Development engineers make determinations based on tensile strength. They use the process compatibility indexes Cpk and Cpm in manufacturing to indicate compatibility with standards and process capability. Making the tensile standards greater than the anticipated stress is known as design margin. Failure results from combined levels of process capability and design margin. While discussing whether the defect ratio is low, the process capability index does not address how failure occurs. Failure stems from the relationship between stress (design margin and process capability) and strength (tensile strength) including variation over time.

7. Types of reliability testing

Fig.3 shows the main types of reliability testing.

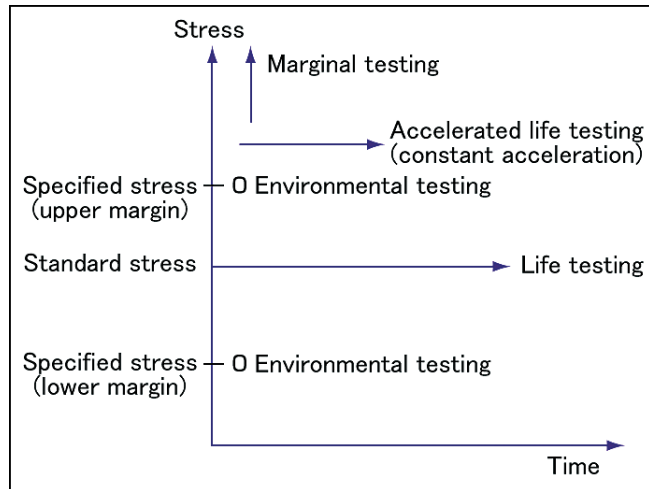


Fig.3 Types of reliability testing

For average stress, life testing is used to test the stability of functions over time. Testing designed to reduce the amount of time involved in life testing is known as accelerated life testing. We must be very careful to stipulate that the failure mechanisms involved in accelerated life testing must be exactly the same failure mechanisms observed in life testing. In other words, constant acceleration must be maintained. Therefore, accelerated life testing need not be within a specified range of stress, but as long as it is at constant acceleration, the test time can be reduced by using the highest stress possible. On the other hand, marginal testing does not pay much attention to time elements, but rather gradually ramps up the stress to discover how much stress the test sample can bear. Therefore, the failure observed may or may not be at constant acceleration. If the observed failure mechanisms are the same as those in life testing, the technical information is relevant.

Environmental testing includes testing within a prescribed range of stress, giving little consideration to elements of time, and checking functional stability in response to stress.

8. Purposes of reliability testing related to type of environmental test equipment

When investigating stress, such as varying temperature and humidity to determine the stability of functions, we consider the purpose of reliability testing using environmental test equipment. This environmental test equipment is not limited to temperature and humidity equipment, but also includes other environmental conditions such as static electricity, vibration, and shock test equipment.

1. Environmental testing: Investigates stability for the functions related to the environment within a prescribed range of environmental stress, such as temperature and humidity stress. The stress on failure mechanisms observed in life testing can be varied. For example, increasing the severity of environmental stress can indirectly increase the severity of the failure mechanism stress, and so functional stability can be investigated within the prescribed range of environmental stress.
2. Accelerated life testing: If we have a direct stress-induced failure mechanism due to such stress as temperature or humidity, accelerated life testing is possible within a constant range of acceleration. By varying the environmental stress that causes the failure mechanism observed in life testing, we can indirectly increase the severity of the stress failure mechanism, and so accelerated life testing can be performed within a constant range of acceleration.
3. Marginal testing: Just as in accelerated life testing, environmental stress is varied, and severe direct stress such as temperature and humidity are applied to investigate where failure can be observed. Also, by varying the environmental stress that causes the failure mechanism observed in life testing, we can indirectly increase the stress of the failure mechanism and thereby investigate the failure margins of that stress.

9. Conclusion

This article has discussed why defects and failure occur and how this understanding can lead to countermeasures against defects and failures. We have looked at Cp, Cpk, and Cpm as means of preventing defects and process capability and design margin as means of preventing failure.

Reliability testing--environmental testing in particular--is widely employed as a means of reliability assurance to prevent defects and failure, but this does not suffice to detect all defects and failure. However, as this article has pointed out, by varying environmental stress, and by increasing its severity, we can indirectly increase the severity of the intrinsic stress of the failure mechanism, thus causing failure. This serves as a crucial measure of reliability assurance. By varying environmental stress, we can use environmental testing to investigate the functional stability of products, and for this reason environmental testing is known as reliability testing.

Nowadays, there is some anxiety about reliability and quality control for Japanese traditional technology. Using environmental test equipment to perform reliability testing is not the total answer to the problem, but by varying environmental stress and by increasing its severity, environmental testing can play a role in analyzing the failure mechanisms observed in life testing.

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