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A Brief Overview of Reliability in General and for Electrical Connectors in Particular

ABSTRACT

Reliability is a term which is commonly used. But the actual meaning of reliability and the problems associated with determining it are often not understood. This paper briefly examines reliability in general and as it relates to connectors. Reliability is defined, the advantages and disadvantages of various methods of determining and expressing reliability are discussed, and the preference for a physics-of-failure approach is explained. Manufacturer and customer responsibilities in determining reliability are also presented.

INTRODUCTION

Customers want reliable products. This is a simple statement with which no one would argue. But what is the reliability of a product? How do we determine product reliability? And can reliability always be determined exactly for all products? By answering these questions, we can gain a better understanding of reliability and of the roles the manufacturer and customer play in determining reliability.

RELIABILITY DEFINED

Reliability is the probability that a part will perform as required for a desired 'time' during which it is subjected to a given set of environmental and/or mechanical stresses.

There are several terms which should be noted in this statement. The phrase 'perform as required' implies that some failure criteria exist. 'Desired time' implies that there is some expected lifetime of the product. This may be in terms of actual time, operating hours, use cycles, etc. 'A given set of stresses' implies that the environmental (temperature, humidity, corrosive agents, etc.) and mechanical (vibration, shock, abrasion, etc.) conditions under which the product must perform are known. Taken together, performance criteria, desired lifetime, and expected stresses define the intended application of the product. **In this discussion, the term 'application' will be meant to include all of these factors.** Using a mathematical analogy, reliability is a function of the performance criteria, desired lifetime, and stresses ($R = f(P,L,S)$). Thus, **reliability is a function of the application of the product, and there will be a different reliability number for every application**.

HOW DO WE DETERMINE RELIABILITY?

There are basically three methods available to determine reliability; actual use, predictive, and physics-of-failure.

Actual Use

The 'actual use' method determines reliability by monitoring the performance of product which is in service. This method provides the most accurate reliability estimate possible as it is a direct measure of the product reliability in actual use. However, much effort is required to set up a system for monitoring the parts. Also, the desired information is not obtained until a relatively long time after some parts are in use. During the study time, the reliability of equipment utilizing the parts, and thus the potential for equipment failure, is unknown. For these reasons, this method has limited application, typically in situations where the functions of equipment utilizing these parts are not critical (thus failures do not cause major problems) or the equipment has systems redundancy so that failure of one part does not prevent the equipment from functioning. A major limitation of this method is that any reliability estimate is valid only for the application studied.

Predictive

Predictive methods attempt to predict the reliability of a part based on some model typically developed through empirical studies and/or testing. An attempt is made to identify critical variables such as materials, application environmental and mechanical stresses, application performance requirements, duty cycle, manufacturing techniques, etc. Typically a base failure rate for the component is assigned, and this is multiplied by factors for each critical variable identified. Examples of this method are US MIL-HDBK-217, Siemens Standard SN29500, and Bellcore TR-NWT-000332. Using this method, reliability can be predicted early (in fact, before parts are made) and effort is minimal. However, the accuracy and validity of the prediction is limited by the quality of the studies used to identify the critical variables and establish factors for each. For a variety of reasons, [8] early field studies indicated, and these predictive models now assume, a constant failure rate over the lifetime of a product. This ignores higher failure rates typically seen at the beginning and end of component life, infant mortality and wear-out, respectively. These models do not take into account the manufacturer's history, ignoring that certain manufacturers provide components with higher reliability due to better process controls, proprietary manufacturing techniques, etc. These issues often result in large variations (1,000 to 10,000 times) in the predicted reliability of a component depending on the model used. A comprehensive review of the basis for and concerns with predictive methods, from which much of the preceding information was gathered, is presented by M. G. Pecht and F. R. Nash in "Predicting the Reliability of Electronic Equipment", Proceedings of the IEEE. Vol. 82, No. 7, July 1994.

Although predictive methods are widely used, the concerns discussed above indicate that one should be very cautious in relying on them. Predictive methods can provide a relatively accurate reliability estimate only for components with few failure mechanisms, limited failure criteria (e.g. working/not working), and in cases where good studies have been done to analyze field failures. **These methods are not useful for components, such as connectors, which are susceptible to many environmental and mechanical stresses, which have failure criteria that vary depending on the system in which they are used, and for which little reliable field failure analysis data exist.** Predictive methods **may** be of some use in providing a relative ranking of reliability between alternative designs in such cases, but the absolute reliability numbers (or failure rates) obtained with these methods will rarely be indicative of the actual performance of the component.

Physics-of-Failure

The physics-of-failure approach requires that potential failure mechanisms of a design be identified and then a test program which will excite these mechanisms be developed. The goal is to cause, at an accelerated rate, the types of failure inducing degradations which would be expected to occur in actual operation.

The major limitation of this technique is the ability to develop a test program which accurately induces the typical degradations at accelerated rates. It is rarely possible to excite all of the potential failure mechanisms simultaneously and at the same acceleration rate. However, with a good understanding of potential failure mechanisms and test technology, useful conclusions about component reliability can be obtained. Therefore, **the physics-of-failure method is preferred since, with a knowledgeably developed test program, it provides more realistic reliability estimates than predictive methods while requiring less time and being easier to apply to a range of operational environments than the actual use method**.

In most cases involving connectors, the physics-of-failure approach is used to obtain an overall qualitative statement of reliability, with quantitative estimates for specific failure mechanisms. In a few cases, it may be possible and desirable to use the physics-of-failure method to obtain a quantitative estimate of reliability for a specific use (e.g., a particular system).

Qualitative But Widely Applicable

In this form, the physics-of-failure approach allows the following type of statement to be made: 'Type X connectors should provide acceptable performance in application Y for a minimum of Z years'. The basis of this approach is to compare the historic performance of connectors in similar field environments to their performance in tests which excite failure mechanisms seen in the field. These comparisons are used to establish test performance criteria which will ensure 'acceptable' reliability (i.e. reliability comparable to that in similar systems which have demonstrated adequate reliability relative to their functions). An example of this type of approach is Bellcore TR-NWT-001217, in which test sequences were chosen based on their history as standard tests in the connector industry. At the conclusion of the Bellcore testing, based on the sequences chosen and the performance exhibited, a connector is qualified for a specific use defined by environment (indoor or outdoor) and system size (I, II, or III, as defined by the number of contact interfaces). For example, if a connector is qualified to outdoor environments, system quality level II, this implies that the connector should perform acceptably in medium size systems in outdoor environments. No number is given for reliability. Acceptable performance implies that based on experience for this size system, the failure rate and lifetime of this connector will be equivalent or better than that which experience has shown to be necessary for the most severe conditions expected in the application classification. **While this method does not provide a numerical estimate of reliability, it is more broadly applicable, and a single test program can indicate acceptable performance for many uses within the overall range of the application classification.**

Customer Obligations - The customer must provide a description of the typical stress levels and qualitative reliability requirements of the intended application. For example, 'this part must be highly reliable in a typical office environment'.

Manufacturer Obligations - The manufacturer must be able to relate the application described by the customer to some commonly used application classification. The manufacturer must also have a knowledge of the testing and test performance requirements which are typically used to demonstrate the ability of the product to perform with the required reliability in the chosen application classification.

Quantitative But Specific

A reliability number may be estimated if the application environment and critical performance requirements can be defined in detail. In this case, it may be possible to develop a test program which can reasonably simulate the actual application environment at an accelerated rate.

Customer Obligations - The customer must be able to provide valid estimates of all critical application environmental and mechanical characteristics, e.g., temperature/humidity profiles, power on/off cycles, corrosive agents, vibration levels, shock levels, particulates, expected number of matings/unmatings, etc. Also, the customer must have application-specific failure criteria for all performance measures, e.g., interface resistance, mating/unmating forces, insulation resistance, temperature rise, etc. Finally, the customer must understand that the reliability given will be highly application-specific. Any change in the application environmental conditions or performance requirements may result in a change in the expected reliability.

Manufacturer Obligations - The manufacturer must have the necessary expertise to develop a test program based on the information supplied by the customer. This includes knowing what stresses will affect the part and how to simulate them at an accelerated rate if possible. Also, a knowledge of methods to properly analyze the test results is required. It will rarely, if ever, be possible to simulate exactly the total test environment in an accelerated manner, especially for stresses which have interactions. Often, stresses are applied individually and reliability numbers for each are calculated. If a single reliability number is desired, either the lowest number is used or, based on some model, the results may be combined. The manufacturer must understand the limits of the testing and analysis being proposed and include a description of these limits and their effects on the reliability prediction.

Only in cases where quantitative reliability statements are possible, can a determination of MTTF or MTBF (mean time to failure or mean time between failures, respectively) be made. However, their use is discouraged. It is not understood by most that MTTF and MTBF do not fulfill the requirements of reliability measures. A simple statement of these values cannot be used to determine the probability of a part performing as required for some period of time because that probability is not defined by the value of MTTF or MTBF but by the underlying statistical distribution of time-to-failure. For example, a product with an underlying statistical distribution of time-to-failure which is approximately symmetrical, has a 50% probability of surviving to MTTF, while a product which has a statistical distribution of time-to-failure which is an exponential distribution has approximately a 37% probability of surviving to MTTF. Therefore, **different products may have the same MTTF or MTBF but different reliabilities**.

MTTF and MTBF are difficult to obtain for electrical connectors. Determination of MTTF or MTBF requires that 1) a large percentage of contacts/connectors actually fail during testing and 2) the time of each failure be known. However, most often few if any failures (however defined) occur during typical connector tests. Thus, obtaining a sufficient number of failures would require either more severe test conditions which may induce unrealistic failure modes, or significantly longer test durations which would increase both development cost and time. Furthermore, during testing the parts would need to be monitored continuously for failures which is possible but much more difficult. Given the fact that better understood and more precise statements of reliability are possible and that determining MTTF or MTBF is more difficult, the use of MTTF and MTBF is not justified.

CAN RELIABILITY ALWAYS BE DETERMINED EXACTLY FOR ALL PRODUCTS

From the discussions above it should be clear that an exact reliability number can be given only in the simplest cases. In typical situations, in which many applications and failure mechanisms exist and in which time, cost, and test technology are limiting factors, we cannot determine the reliability of a product exactly. Estimates of reliability, either quantitative or qualitative, must be used. In the case of complex, multiple application components such as connectors, which are susceptible to multiple and sometimes interacting environmental and mechanical stresses, the only method which can provide good estimates of qualitative or quantitative reliability at a reasonable cost and in a reasonable time is the physics-of-failure method.

SUMMARY

Reliability, the probability that a part will perform as required for a desired time during which it is subjected to a given set of environmental and/or mechanical stresses, can be determined exactly only in the simplest of cases, which are not typically those of interest. In the vast majority of situations, the complexity of the application (defined in lifetime, stresses, and performance criteria) makes it impossible to determine an exact reliability number. Predictive techniques (e.g. MIL-HDBK-217), which are limited by the quantity and quality of field data which are available, cannot possibly combine all of the potential factors that must be considered for components, such as connectors, which are placed in multiple applications and which are susceptible to multiple and interacting stresses. Instead, a physics-of-failure approach must be used to predict the reliability of most components. This approach may provide either a quantitative or qualitative statement of reliability. The customer must be able to provide the manufacturer with a description of the application at a level of detail appropriate for the exactness of the reliability estimate desired. The manufacturer must have the knowledge and expertise to use the description to develop a reliability test program which provides the customer with the appropriate information.

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