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Estimation of the reliability of electrical connectors

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National foreword

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Estimation of the reliability of electrical connectors

Estimation de la fiabilité des connecteurs électriques

INTERNATIONAL ELECTROTECHNICAL COMMISSION

COMMISSION ELECTROTECHNIQUE INTERNATIONALE

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ESTIMATION OF THE RELIABILITY OF ELECTRICAL CONNECTORS

FOREWORD

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Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC TS 61586, which is a technical specification, has been prepared by IEC technical committee 48: Electrical connectors and mechanical structures for electrical and electronic equipment.

This second edition cancels and replaces the first edition published in 1997. This edition constitutes a technical revision.

The main technical changes with regard to the previous edition are as follows:

- A specific “basic” testing protocol is defined which utilizes a single test group subjecting connectors to multiple stresses.
- Additional information is provided concerning test acceleration factors.
- A discussion of the limitations of providing MTTF/MTBF estimates for connectors has been added.
- The bibliography has been expanded.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
48/563/DTS	48/568/RVC

Full information on the voting for the approval of this technical specification can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

The reliability of electronic assemblies depends on the reliability of the passive electrical connections between the active components, as well as on the reliability of the components themselves. There is a common perception that interconnections, specifically connectors, are a major source of failures, often of the "no fault found" variety, in electronic assemblies. Whether this perception is true is not the subject of this technical document, but connector reliability is a concern. Much of the increasing attention being given to reliability of electrical connectors focuses on the basic question of how the reliability of electrical contacts and connectors can be meaningfully determined.

The definition of reliability which will be assumed in this document is the following:

> The probability of a product performing a specific function under defined operating conditions for a specified period of time.

Reliability is therefore a function of:

a) The expected lifetime of the part.
b) The application stresses (electrical, thermal, mechanical, chemical, etc.) the part will be subjected to during its life.
c) The specified failure criteria.

Since these factors will be different for every application in which the connector may be used, a given connector will have a different reliability for every application in which it may be used. Therefore, a connector manufacturer cannot provide a reliability estimate for a contact or connector until the customer has provided a detailed description of the factors listed above for the application in which the connector will be used. To provide a numerical estimate of connector reliability, the manufacturer will then need to use the information provided by the customer to design a test program to simulate the application intended.

Some factors which are to be taken into account in addressing this definition are the subject of this document. The reliability assessment methodology to be discussed centres on appropriate statistical analysis of test data, based on proper consideration of the following issues.

d) The active degradation mechanisms are to be identified and categorized by their importance for the application.
e) Appropriate environmental tests, with corresponding acceleration factors, where practical and appropriate, and exposures, are to be determined for these degradation mechanisms.
f) Use of a test sequence which provides an opportunity for the interaction of the potential degradation mechanisms as is necessary to realistically simulate the effects of the expected application.
g) The statistical approach to estimating reliability from the test data is to be agreed upon.
h) An acceptance criterion appropriate for the application of interest is to be established.

Items d), e and f) relate to the ability of the product to continue to perform its designated function under the degradation mechanisms it is subjected to in its operating environment. In addition, the need for an acceleration factor is fundamental to assessing the operating life of the product.

Item g) is necessary, since the reliability definition is based on probability which requires statistical treatment of appropriate data.

Finally, item h) is a result of the fact that the reliability to be assessed is based on the product performing a defined function.

The level of knowledge and understanding available to address these issues varies appreciably. Each topic is considered in a separate subclause.

It is to be noted that there are a number of other factors which have an effect on connector reliability. Among these are:

i) the connector manufacturing process;

j) assembly/application procedures of the equipment manufacturer;

k) abuse/misuse of the equipment by the end user.

The importance of these application or extrinsic factors cannot be denied and may well be the final determinants of connector reliability. However, extrinsic factors are highly variable and, therefore, difficult to account for in any estimation of reliability. For these reasons, this document will focus on intrinsic connector reliability, i.e. the reliability of the design/materials of the connector itself as evaluated by the procedures listed previously. This intrinsic reliability represents the greatest reliability which the connector can achieve. The extrinsic factors will result in a reduction in reliability.

It is also to be noted that the approach to reliability estimation in this document differs significantly from that based on a base failure rate which is modified by application-specific factors as, for example, in IEC 60863 or MIL Handbook 217.

The two approaches are related in that the base failure rate could be determined by a different statistical treatment from the same data which are used in assessing reliability by the method to be discussed. The test environments and exposures would determine the standard conditions which are defined for the base failure rate. In addition, the derating factors used in the failure rate approach can, in principle, be derived from the same data used to determine acceleration factors in the proposed statistical method.

The advantage of the approach recommended in this document is that the standard conditions, acceptance criteria, and statistical treatment are specifically defined for the application under consideration. This is in contrast to a base failure rate starting point which is frequently poorly defined and documented.

ESTIMATION OF THE RELIABILITY OF ELECTRICAL CONNECTORS

1 Scope

This technical specification deals with the estimation of the inherent design reliability of electrical connectors through the definition and development of an appropriate accelerated testing programme. The basic intrinsic degradation mechanisms of connectors, which are those mechanisms which exist as a result of the materials and geometries chosen for the connector design, are reviewed to provide a context for the development of the desired test programme. While extrinsic degradation mechanisms may also significantly affect the performance of connectors, they vary widely by application and thus are not addressed in this document.

2 Normative references

There are no normative references in this document

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

4 General considerations

4.1 General

Degradation leading to failure of a contact or connector can occur in many ways. For our purpose, it is convenient to divide the mechanisms into two categories, intrinsic and extrinsic.

4.2 Intrinsic degradation mechanisms

As mentioned in the introduction, intrinsic degradation mechanisms are those related to the design and materials of manufacture of the contact or connector. Examples are corrosion, loss of normal force through stress relaxation, and excessive Joule heating leading to temperature-related degradation.

4.3 Extrinsic degradation mechanisms

Extrinsic degradation mechanisms are related to the application of the contact or connector. Examples are inadequate controls during manufacture of the connector, improper assembly processes during equipment manufacture, contamination during application, degradation caused by use of the connector outside its rated temperature range (both ambient and enclosure-related) or by application of currents exceeding the product specification (in both single and distributed modes), and contact abuse resulting from improper mating practices (mating at excessive angles, pulling on cables, etc.) by the end user.

4.4 Control of extrinsic degradation

Extrinsic degradation can be taken into account by incorporating design features in the connector to reduce the potential for such degradation by proper specification of product performance by the connector manufacturer, and by proper use of the available information by the equipment manufacturer and end user. This is a joint responsibility which merits attention. The connector manufacturer can include strain relief for cables, finishes on contacts, improved crimps and other features intended to provide robustness against extrinsic degradation, but these can always be overcome through abuse or misapplication by the user. The concept of user includes the electrical equipment manufacturer as well as the ultimate user of the equipment. However, extrinsic degradation mechanisms, due to their variety and application dependence, are not something which can be straightforwardly analyzed, modelled or simulated. This limitation makes estimation of the effects of extrinsic degradation mechanisms on connector reliability problematic despite the fact that, as mentioned, such degradation mechanisms may be the major determinant of connector reliability in actual use. For this reason, when evaluating a system in which a connector will be used, an estimate of the reliability of a connector based on testing of the connector in isolation should be primarily used in conjunction with estimates of reliability of other components of the system to provide an initial prediction of system reliability. But as with any other component, the actual reliability of the connector in a system can be determined only through appropriate testing of the system in which it is used.

4.5 Failure effects, failure modes and failure (degradation) mechanisms

4.5.1 General

Given the context of the previous remarks, in this document the discussion is limited to a few aspects of intrinsic degradation, in order to describe an approach to connector reliability evaluation. For clarity, it is important to distinguish between failure effects, failure modes and failure (degradation) mechanisms.

A failure effect is the specific problem in operation which the customer will see. Examples specific to contact and connector failures are loss of signal, loss of power, overheating/burning, shorting, etc.

A failure mode is a physical description of the change in a part which may directly or indirectly result in a failure effect observed by the customer. Examples of failure modes specific to connectors or contacts are high resistance, reduced normal force, low insulation resistance, etc.

A failure or degradation mechanism is the physical, chemical or other process which resulted in the failure mode.

Note that while the term failure mechanism is often used, the term degradation mechanism more clearly describes what is being discussed. A degradation mechanism can often occur without causing failure if the level of degradation remains below some critical value. Therefore, for the remainder of this document, the term degradation mechanism will be used.

4.5.2 Failure modes

Only one failure mode, the variation in contact resistance, will be considered in this document, although many others exist, both mechanical (broken latches, bent pins, etc.) and electrical (crosstalk, leakage between contacts, etc.).

4.5.3 Degradation mechanisms

Three intrinsic degradation mechanisms which are well understood and which are known to have a major impact on contact resistance stability are considered:

- corrosion;
- stress relaxation;
- plating wear.

Corrosion of the contact interface causes an increase in contact resistance due to the formation of non conductive material in the contact interface. Stress relaxation results in loss of contact normal force which in turn can lead to increased contact resistance either directly, in the case of extreme loss of normal force, or indirectly through increased susceptibility to mechanical or corrosive degradation. Plating wear can lead to increased contact resistance if wear-through occurs to the contact underplate or base material, both of which are typically more susceptible to corrosion than the surface plating materials. These degradation mechanisms result, generally, in increases in contact resistance. The amount of degradation which occurs before reliability is affected depends on the application in which the connector is used and is, therefore, application specific, as will be discussed. A primary concern is that individually these degradation mechanisms may cause little or no increase in resistance. However, they can interact to cause contact failure.

Experience with the product, or with similar products or applications, allows us to categorize and rank the degradation mechanisms. Such categorization and ranking is necessary to define an appropriate testing programme and identify, when possible, how the test conditions relate to field performance and lifetime.

5 Test methods and acceleration factors

The objective of reliability testing is to cause in the test specimens levels of degradation which accurately reflect the levels of degradation which will be found in parts when they are used in the application being simulated. Once these levels of degradation have been caused by subjecting the test specimens to the specified test conditions, the performance of the test specimens can be evaluated against appropriate application failure criteria and the reliability of the parts in the application simulated by the test can be estimated. To be of use, the testing needs to accelerate the rates of degradation so that the required performance evaluation can be completed in a reasonable time. To know how much application time has been simulated by the test, it is necessary to know the acceleration factor of the test. In simple terms, the objective is to be able to state that *X* days of exposure to the test conditions used, which may activate a given degradation mechanism, are equivalent to *Y* years of service in the expected application conditions. The acceleration factor between the test exposure and field exposure is the time in the field which the test simulated divided by the time in the test. Note that other test duration units such as cycles may be used in place of time as appropriate.

Unfortunately, there are only a few tests appropriate for contacts and connectors for which such acceleration factors have been developed or determined. One of these tests, MFG (mixed flowing gas) exposure, stresses the degradation mechanism of corrosion and is primarily designed for use on contacts with noble metal based plating systems. Work to develop various MFG tests has been done at several laboratories in different countries and in some cases provides the required data from which acceleration factors can be derived.

Another test exposure for which acceleration factors can be determined is dry heat exposure, also known as temperature life or heat age exposure. This test accelerates the degradation mechanism of stress relaxation. Stress relaxation data are available for a broad range of copper alloys used in connectors. Consideration of these data will allow an acceleration factor to be defined for temperature life testing. However, stress relaxation is not linear with time. Therefore given a known application operating temperature and a specified test temperature it is still not possible to determine the acceleration factor of the test since the acceleration factor will change as the time in test increases. As a result of this non linear response of stress relaxation with time, increasing the test duration by a factor of X will not increase the lifetime simulated by the test by the same factor of X. In fact for a given test temperature, small increases in the lifetime which the test is used to simulate can cause very large increases in the required duration of the test. A method for determining the acceleration factor for dry heat exposures is provided in informative Annex A.

An important issue to note with stress relaxation testing is that stress relaxation relates only to the contact normal force and not directly to reliability as evaluated by resistance stability. Studies have shown that a large reduction in stress relaxation, and therefore normal force, can occur with minimal change in resistance Therefore, the effects of stress relaxation on contact reliability as assessed by contact resistance stability shall be evaluated in conjunction with other test exposures following a temperature life exposure. For example, exposing contacts in a mated state to a dry heat test and then exposing the same contacts to a vibration test which may cause motion at the contact interface may reveal a reduction in resistance stability which would be expected in actual use of the contact but which would not be evident through the use of a dry heat test only.

Other tests applied to electrical contacts and connectors but for which no acceleration factors are typically defined include:

- temperature cycling with high humidity typically used to assess corrosion effects in non noble metal plated contacts;
- mating/unmating or durability cycling used to assess wear effects;
- mechanical shock and/or vibration used to assess wear effects in general, fretting corrosion of non noble plated contacts, and fretting corrosion of noble plated contacts in which the noble metal surface plating has been worn through in vibration or other testing such as durability cycling performed prior to vibration;
- salt spray used to assess corrosion effects for products used in harsh environments such as marine applications and automotive applications in which the connector is directly exposed to the outside environment.

As these tests have no established acceleration factors, when used in isolation they indicate only the relative performance of connectors. The resulting data indicate only the behaviour of the connector system under the tests. They are not reliability tests yielding data on which estimates of behaviour under operating conditions can be based. However, these tests can be used within a properly designed sequence of test exposures which also includes MFG exposure and/or dry heat exposure to create a useful estimate of contact and/or connector reliability.

6 Basic contact and connector reliability testing protocol

The primary degradation mechanisms of concern when assessing changes in contact resistance may occur individually without having a significant detrimental effect on contact resistance. For example, environmental corrosion of a contact surface can create corrosion products around the contact interface. But as the actual microscopic points of metal to metal contact within the interface are essentially gas tight, the corrosion processes which occur in most applications will take much longer than the expected lifetimes of contacts before disrupting these points of contact and causing a noticeable increase in resistance. Similarly with stress relaxation, a significant decrease in contact normal force may occur without a significant increase in contact resistance. During mating, to create a clean metal to metal interface with a low electrical resistance, a relatively high normal force may be required, especially for non noble plated contacts. This force is necessary to displace oxides and other non conductive materials which may have accumulated the contact surface prior to mating. However, once this interface is created, in the absence of stresses which will cause the contact interface to move, the normal force required to maintain the low resistance interface is much less than that which was required to create the interface initially. Thus, if the contact interface does not move, normal may be reduced significantly without a detrimental increase in resistance. Since the primary degradation mechanisms in contacts have limited effect in most cases when occurring individually, a well designed contact will usually exhibit only a few mΩ of resistance change in testing when subjected to individual stresses which activate a single degradation mechanism.

However, in actual use, contacts are subjected to multiple stresses which can activate all of primary degradation mechanisms simultaneously. And these stresses can interact directly and indirectly to cause changes in resistance which are sufficiently large to cause failures in the systems in which the contacts are used. For example, an environment which may cause minimal corrosion on a new contact with intact plating may cause significant levels of corrosion if the contact plating has been worn through due to the action of mating and unmating or vibration. Further, the motion which caused the plating damage allowing corrosion to occur will also shift the location of the contact potentially moving it into a location where corrosion exists. If in addition to these stresses, stress relaxation has occurred causing a reduction in contact normal force, the contact interface will have a lower mechanical stability. As a result, vibration levels and temperature cycling which may not have caused motion at the interface when the contact was new may now cause motion. And with the reduced normal force, the ability of the contact to displace non conductive material such as corrosion products will be reduced. In addition, the reduced normal force may make the contact susceptible to small (typically less than 0,1 mm) cyclic motions when subjected to vibration or temperature cycling. If these motions do occur in non noble metal plated interfaces or in noble metal plated interfaces in which the non noble metal under-plating or base metal is exposed, the degradation mechanism of fretting corrosion can occur and cause increased resistance.

Because it is the interactions of these degradation mechanisms which are most likely to cause contact failures, an effective reliability test protocol shall include tests which can potentially activate all these mechanisms in the same parts and in conjunction with potential contact interface motion drivers. A basic reliability test protocol should thus include the following:

a) Tests such as vibration and durability cycling which can cause damage to plating.
b) Tests such as mixed flowing gas (MFG) for noble metal plated contacts and temperature cycling with humidity for non noble plated contacts which can cause corrosion. Vibration and temperature cycling may also cause fretting corrosion in non noble plated contacts or noble plated contacts with damaged plating.
c) Dry heat exposure to accelerate stress relaxation and cause reduced normal force.
d) Tests such as temperature cycling, thermal shock, vibration, and mechanical shock which can cause motion at the contact interface.

Additional test exposures may be included as needed depending on the intended application. For example, power contacts which carry sufficient current to create increases in temperature sufficient to accelerate various degradation mechanisms should be subjected to current cycling. Testing of contacts to be used in areas of high particulate exposure may include dust exposure.

For each test method included in the reliability test sequence, the level of stress applied and the duration should be chosen such that the exposure causes a degradation which equals that expected to be caused during the life of the product in its intended application. In other words, they should place the test specimens in an end-of-life state. Therefore, it is desired that there be known acceleration factors for all the tests used. But as noted earlier, reliable acceleration factors are known for only dry heat stress relaxation tests and some MFG corrosion tests. Fortunately, due to the way the contact interfaces respond to certain stresses, a lack of acceleration factors for some tests does not prevent them being used in reliability evaluations.

One of the most important aspects of contact interface behaviour which allows tests without acceleration factors to still be used in reliability testing is that the degradation of contacts to certain stresses is not continuous. In other words, certain stresses do not cause a change in the contact interface until they cross some threshold level of severity. Further, once crossing a certain level of stress, these degradation mechanisms will then occur very quickly. One example of this type of stress is temperature cycling. As temperature increases and decreases, expansion and contraction of the contact or connector components will occur resulting in mechanical forces on the contact interface. Unless these forces are sufficient to overcome the frictional force at the interface, which is a function of the normal force and the coefficient of friction between the contact surface materials, no motion and thus no degradation will occur. But if the temperature cycles are at a level to cause motion at the interface in a non noble plated contact, fretting corrosion will occur and significant resistance change will be identified in relatively few test cycles, e.g. fewer than 1 000 cycles in tin interfaces and fewer than 100 in nickel interfaces.

Another common test that behaves in this manner is vibration. Within some domain of frequency, amplitude and/or acceleration levels, no movement will be caused in the contact interface. Beyond these levels, once movement is caused millions of cycles of motion will often occur in less than an hour which may cause significant wear and possibly fretting corrosion depending on the metallurgy of the contact interface.

When these types of tests, which do not cause degradation below some stress threshold and then can potentially cause rapid degradation above these levels, are used in a reliability test program they essentially determine if the application stresses are too severe for the contact or connector design. Given this, a critical aspect to ensure when these tests are used is that they do not significantly exceed the expected application stresses. If they do, they may cause motions in the contact interface which will not occur in actual use and thus cause failures in testing which are not representative of performance which would occur in the application.

Another category of tests which do not have an acceleration factor but which can still be used in a reliability test program includes tests which can be performed at the same level and rate as the expected application stress and still place the product in its expected end-of-life degradation state in a reasonable amount of time. One example from this category of tests is durability, or mate/unmate, cycling. Obviously one unmate/mate cycle in a test is equivalent to one unmate/mate cycle in the application. Therefore, if during the life of a product it is expected that 100 durability cycles will occur, then a reliability test duplicating this with 100 cycles can be done.

A valid reliability test program can therefore be created using tests which both do and do not have known acceleration factors if those without known acceleration factors fit in one of the categories described above. Further, as was previously discussed, the reliability test shall be designed such that all the critical degradation mechanisms can interact. Ideally the design would excite all the degradation mechanisms simultaneously. In practice this is not possible. The tests required have conditions which are mutually exclusive. For example, MFG corrosion tests are normally run at temperatures in the range of 20 °C to 40 °C whereas a dry heat stress relaxation tests are run at temperatures exceeding 90 °C. Because of this, connector reliability test programs shall apply the required stresses using a sequence of test exposures. The sequence in which the tests are applied then becomes important. For example, at least some durability cycling which may damage plating needs to be performed before corrosion testing begins since in actual use the plating may be damaged when corrosion stresses occur.

Based on the issues discussed above, a core test protocol to evaluate reliability using resistance change as the performance criterion can be defined for contacts and connectors. The core testing shall place the contacts in an end-of-life state for the degradation mechanisms of wear, corrosion, and stress relaxation and then subject the test specimens to appropriate potential motion drivers such as temperature cycling and vibration. For a non noble metal plated contact system, the core testing will be:

Durability cycling: This can potentially cause plating damage or wear making the contact more susceptible to subsequent corrosion tests. The number of cycles will typically be representative of the number expected during the life of the product in the intended application. If the product is expected to be mated and unmated regularly during life, the test cycles may be performed in sets starting before and then performed periodically during a corrosion test.

Dry heat: This test will cause stress relaxation in mated contacts. It is done before fretting corrosion stress tests such as temperature cycling and vibration as contact interface motion which causes fretting corrosion will be more likely when contact normal force has been reduced due to stress relaxation.

Temperature cycling: This test may cause interface motion leading to fretting corrosion. For tin plated interfaces it will typically require 500 to 1 000 cycles before the effects of fretting corrosion are seen. Nickel interfaces typically exhibit the effects of fretting corrosion after 50 to 100 cycles. As was noted previously, the temperature extremes used in the test may be beyond those in the expected application to provide a margin of safety. However, setting the test conditions significantly beyond the application conditions may cause interface motion and thus failures which are not representative of the performance which will occur in the application.

Vibration: This test may cause interface motion leading to wear or fretting corrosion or both. If the vibration level causes motion at the interface, significant changes in resistance will typically occur within a few (typically one to eight) hours. As was noted previously, the maximum frequency and amplitude/acceleration levels used in vibration testing may be beyond those in the expected application to provide a margin of safety. However, setting the test conditions significantly beyond the application conditions may cause interface motion, and thus failures, which are not representative of the performance which will occur in the application being simulated. Further, if vibration is not a significant stress in the application environment, this test should not be included.

For a noble metal plated contact system, the core testing will be:

Durability cycling: This can potentially cause plating damage or wear making the contact more susceptible to subsequent corrosion tests. The number of cycles will typically be representative of the number expected during the life of the product in the intended application. If the product is expected to be mated and unmated regularly during life, the test cycles may be performed in sets starting before and then performed periodically during a corrosion test.

Dry heat: This test will cause stress relaxation in mated contacts. It is done before fretting corrosion stress tests such as temperature cycling and vibration as contact interface motion which causes fretting corrosion will be more likely when contact normal force has been reduced due to stress relaxation. Note that contacts with noble platings will typically exhibit fretting corrosion only if the surface plating has been worn through thus exposing the non-noble under-plate, if used, or base metal.

Mixed flowing gas: This may cause corrosion due to poor quality plating or damage to plating from assembly, mate/unmate cycling, etc. It may also cause corrosion in areas which do not contain noble plating. This corrosion may occur very near to the contact area or may spread across non-noble or unplated surfaces into the area surrounding the contact interface. Subsequent motion drivers may cause the contact interface to shift into an area of corrosion. Consideration should be given to whether the connector should be mated or unmated during part or all of the exposure. Also, if the connector will be unmated during any of the exposure, typically only one half, plug or receptacle, of each connector pair will be exposed. The half chosen for unmated exposure should be based on the intended application. An example would be a cable used in a computer workstation or server to accommodate future addition of peripheral devices such as a data storage device. This cable would include several plugs which are not initially used and thus may remain in an unmated state for two to five years of service in the system prior to being mated to a new storage device. The receptacle on the new storage device will be in a virgin state. To simulate this application then, the plug used on the cable would be exposed in an unmated state to an MFG test for a duration simulating up to five years of use in the intended application. After this it would be mated to an unexposed receptacle and the pair would then additional MFG exposure of the mated pair would be done for a duration simulating the additional expected lifetime of the intended application.

Temperature cycling: This test may cause interface motion resulting in the contact interface shifting to an area with corrosion. If non noble under-plate or contact base metal are exposed prior to temperature cycling fretting corrosion may occur during this test. As was noted previously, the temperature extremes used in the test may be beyond those in the expected application to provide a margin of safety. However, setting the test conditions significantly beyond the application conditions may cause interface motion, and thus failures, which are not representative of the performance which will occur in the application.

Vibration: This test may cause interface motion resulting in the contact interface shifting to an area with corrosion. If non noble under-plate or contact base metal are exposed prior to this test fretting corrosion may occur during this test. If the vibration level causes motion at the interface significant changes in resistance will typically occur within a few (typically one to eight) hours. As was noted previously, the maximum frequency and amplitude/acceleration levels used in vibration testing may be beyond those in the expected application to provide a margin of safety. However, setting the tests conditions significantly beyond the application conditions may cause interface motion, and thus failures, which are not representative of the performance which will occur in the application. Further, if vibration is not a significant stress in the application environment, this test should not be included.

In addition to the core testing included above, other testing may be added if appropriate for the intended application conditions. Examples of such tests are dust contamination, thermal shock, mechanical shock, electrical current cycling, etc. Consideration shall be given to the appropriate placement of such tests within the test sequence. For example, if a dust exposure is to be included, should it be included at the beginning of the test sequence as might be appropriate for a part which may be unmated for some time in an application before being mated? Or would it be included after mating but before other stresses such as vibration, which might better represent a use condition of parts which are mated as soon as the system they are to be used in is assembled? Again, the choice would depend on the intended application for which the test program is being designed.

The protocols described above serve as a basis for developing a connector reliability test program. For a specific connector type, determining the specific test methods and conditions to be used and the order in which they should be applied in the reliability test sequence requires a full understanding of contact and connector behaviour. It is also necessary that the application stresses be identified and that their levels be known.

7 Reliability statistics

7.1 Basic statistical approach to estimating reliability for variables data

This clause focuses on reliability predictions for failure criteria based on variables data, i.e. data for performance criteria which are measurable values such as contact resistance, temperature increase, mating force, etc. Variables data have distributions to which a variety of statistical treatments can be applied.

Failure criteria based on attribute data, i.e. data which do not represent a measurable value but which consist of simple statements such as good/not-good or pass/fail will not be discussed in this document. Attribute data includes criteria such as intermittent electrical discontinuity, fracture of a latching mechanism, etc. The statistical treatment of attribute data is rather limited, and large sample sizes are needed to provide confidence in the conclusions. Also, given the typically small sample sizes used in testing, in most situations when contact or connector failures of these types occur, a single failure of the product would normally be indicative of unacceptably low product reliability. No reliability estimate is thus required.

As discussed above, a reliability test program for connectors will subject parts to a sequence of environmental, mechanical, electrical, and possibly other stresses with the goal of creating a level of degradation in the parts similar to that which will occur over the lifetime simulated by the test sequence. Once in this end-of-life state, measurements are made of the desired performance factor, e.g. contact resistance, mating force, temperature increase at a specified current, etc. Given a specified failure criterion, these test data may then be analyzed using a variety of statistical techniques to determine the probability that any given part will perform without failing during the lifetime which was simulated in the testing performed. This probability represents the reliability of the parts.

A detailed explanation of the use of reliability test data to provide estimates of product reliability will not be provided here. These techniques are not specific to connector reliability and have been covered extensively in texts on the topic of reliability as well as in some IEC standards, e.g. IEC 61709. Further the specific analysis required will vary depending on the characteristics of the data being analyzed and a full discussion of this is beyond the scope of this document. But an overview of the basic steps is provided here.

The fundamental process in estimating the product reliability from appropriate test data requires that the data first be fit to a distribution with known characteristics. The distribution should be one known to be typical of well behaved data of the type being analyzed. For example, well behaved contact resistance and change in resistance data will typically exhibit a normal or lognormal distribution. Once the data are fit to an appropriate distribution, the characteristics of the distribution are used to estimate the range of performance expected in the entire population of parts beyond the small number of parts actually tested. These estimates shall also include an adjustment based on a tolerance-factor. This factor will be a function of sample size, required confidence level, and the reliability level estimated.

7.2 Contact vs. connector reliability

When considering what distribution may be appropriate to describe the data and thus used as a basis for estimating the reliability of the product, special consideration is required when estimating the reliability of individual contacts versus estimating reliability for a connector with multiple contacts. In the case of a multiple position connector, the connector is typically considered to have failed if any contact within the connector fails. If all contacts within the connector responded statistically identically to the stresses applied, i.e. their performance is not affected by their position within the connector, the connector reliability will simply be the estimated individual contact reliability raised to the power of the number of contact positions in the connector as shown in the formula below:

$$R = r^{\mathrm{n}}$$

where:

R is the connector reliability;

r is the individual contact reliability;

n is the number of contact positions.

It is important to employ appropriate statistical techniques to confirm contact performance is actually independent of position in the connector housing before estimating connector reliability on this basis. In fact, in many cases, due to positional effects in the connector, it is likely that each contact will react differently to the stresses which are applied to the connector. An example of this is the degradation of a contact caused by the internal heating which occurs when a current is applied. In a multiple position connector, contacts along the outer walls will dissipate internally generated heat much more efficiently than contacts in the centre of the connector with the same current applied. Therefore, the outer contacts will operate at a lower temperature than the inner contacts. This will affect the rate of some degradation mechanisms, e.g. stress relaxation, resulting in a slower rate of degradation for the outer contacts as compared to the rate for the inner contacts operating at a higher temperature.

Corrosion rates can be significantly affected by the position of the contacts within a connector housing. Noble metal plated contacts in positions along the outer walls of connectors with three or more rows of contact may exhibit faster rates of environmental corrosion especially if the connector is exposed to pollutant gasses in an unmated configuration. Non-noble metal plated contacts may be more susceptible to fretting corrosion in certain positions within connectors due to the how the housing reacts to vibration, mechanical shock, temperature cycling, and thermal shock. In addition, plating wear resulting from various stresses such as mate/unmate cycling, vibration, mechanical shock, temperature cycling, thermal shock, etc., can vary between different connector positions leading to increased corrosion rates for contacts experiencing the greatest level of contact wear.

Based on the preceding discussion, estimating connector, rather than contact, reliability shall in most cases be done under two assumptions which are true in the majority of cases:

- The failure of any contact within a connector constitutes failure of the connector
- The behaviour of the contacts will be influenced by the position they occupy within the connector

One effect of these assumptions is that the reliability of connectors will be dominated by the performance of the contacts in those positions which typically have the greatest level of degradation. Therefore, estimates of the reliability of connectors using variables data will not be based on the performance data from all contacts in the connector. Instead, the estimate will be based on a subset of the data. This subset will consist of the measurement made of worst performing contact within each connector tested. For example, consider a test performed using 10 connectors, each containing 20 contacts. If the performance measure of interest is increased contact resistance, then a total of 200 contact resistance readings would be made at each reading interval. However, for the purpose of estimating connector reliability, the data set to be analyzed would contain 10 values consisting of the readings for the contacts with the largest increase in resistance from each connector.

Another effect of the assumptions stated above is that the subset of data used for the estimate will not be well characterized using typical distributions such as normal and log-normal distributions. As the values being analyzed are the worst case values (smallest or largest) from each connector, they represent only the extreme portions of the distributions of the population of all contacts from which they were selected. For these reasons, a data set consisting of individual extreme values taken from each of several test specimens which provided multiple readings are usually best evaluated using an appropriate extreme value distribution. An example of this approach is provided in Annex B.

7.3 Estimating contact / connector reliability estimates in terms of MTTF/MTBF

A common method of stating reliability is in terms of MTTF (Mean Time to Failure) in the case of non-repairable devices, or MTBF (Mean Time Between Failures) in the case of repairable devices. These values are often mistakenly interpreted as indicating the operating time at which half of the parts can be expected to have failed, thus representing the lifetime for 50 % reliability. However, the actual reliability at MTTF or MTBF depends on the time-to-failure distribution of the product in some application. If this distribution is symmetrical, then 50 % of the product will fail before reaching MTTF or MTBF. However, if the time-to-failure distribution is not symmetrical, then the reliability at MTTF or MTBF may be greater or less than 50 % depending on the shape of the time-to-failure distribution. For example, a product with a constant failure rate will exhibit an exponential time-to-failure distribution resulting in approximately 63 % of product failing before MTTF or MTBF. Thus in this case reliability at MTTF or MTBF is just 37 %.

In order to define the time-to-failure distribution in a reliability test, it is necessary to have data documenting the length of test exposure at which each failure occurred. If failure is a result the interaction of multiple stresses, then collecting the necessary information to define the time to failure distribution would require that the test be able to simultaneously create all the necessary stresses at the same accelerated rate. As has already been discussed, it is not possible to perform such a reliability test with electrical contacts. Therefore, it is generally not possible to characterize the expected lifetime time-to-failure distribution using data from a connector reliability test. This prevents providing an estimate of MTTF or MTBF, unless some assumption is made for the characteristic time-to-failure distribution of the product.

8 Acceptance criteria

A critical question in any reliability test program is what is the appropriate acceptance criterion to use in calculating contact reliability? Consider two possibilities: the product specification and an application-related value. For reliability testing the product specification criteria are **not** the proper choice. The product specification values have a reliability aspect to them in the sense that the manufacturer has tested the product design to ensure that the specified values will be maintained under the test conditions stated in the product specification or in a general category of applications. Generally, the actual application conditions will not be known. This is especially true for contacts and connectors which are suitable for many applications and, in fact, may perform under different conditions and with different acceptance criteria even in the same system. To account for these unknown factors, the product specification value includes an engineering safety/ignorance factor. In other words, connector product specification acceptance criteria typically require greater performance than necessary for most applications in which the connectors will be used.

In a particular application, on the other hand, a user will have established a value, such as maximum contact resistance, at which the system ceases to function properly. Using contact resistance as an example, this value might be over 100 mΩ in a signal application, or under 0,5 mΩ for a high current contact. The acceptance criterion, which shall be known when determining a reliability estimate, shall thus be based on the application-specific value and not the product-specification value. The requirement on statistical confidence limit and reliability in the particular application should then be applied with this application-specific acceptance criterion as the acceptance limit.

Simply stated, the correct acceptance criterion value to use in estimating contact or connector reliability is the maximum or minimum value which can be tolerated without failure in the actual application for which the reliability estimate is being developed. The typically more stringent product specification acceptance criteria are neither required nor appropriate in a reliability test program because, in a reliability test program, the actual application conditions and requirements will have been defined, thus the engineering safety/ignorance factor is largely eliminated.

9 Summary and conclusions

Some approaches to estimating the reliability of electrical contacts and connectors have been discussed. Estimation of connector reliability is a complex issue for at least two reasons. First, extrinsic or application-related degradation mechanisms, which may be the major factors in determining connector reliability, are highly variable and difficult to identify and quantify. Second, the intrinsic degradation mechanisms which define the fundamental reliability of a given connector, determined by its design and materials of manufacture, require the definition of an acceleration factor to relate laboratory exposure to application lifetime. Such a factor cannot be determined for many potential connector degradation mechanisms. Given these limitations, a reliability estimation programme to work within these limitations is suggested. The recommended approach includes statistical analysis of test data, and considers the active degradation mechanisms, determination of appropriate environmental tests with corresponding acceleration factors and exposures, statistical analyses appropriate for the test data, and establishment of appropriate acceptance criteria. Each of these issues was treated separately. Finally, multi-position connectors were discussed.

The recommended reliability estimation programme consists of the following:

a) Determining an application-specific acceptance criterion for contact resistance. A criterion is also required for every other performance factor to be included in the programme.
b) Developing a test programme to address the anticipated degradation mechanisms operative in the application. The program should apply multiple stresses to single groups of parts to allow interaction of degradation mechanisms as will occur in actual applications.
c) Deriving acceleration factors, when possible, for the specified tests. If an acceleration factor cannot be defined, no reliability statement can be made, since the operating lifetime simulated by the test exposure cannot be determined. However, for stresses primarily intended to potentially drive contact motion, an acceleration factor may not be required.
d) Deciding on the statistical treatment appropriate to the data from the reliability estimation programme.
e) Estimating the component reliability.

All of these considerations depend heavily on engineering judgment. Both the connector manufacturer and the user should agree on the content and approaches to be specified in these steps, in particular, and the reliability estimation programme, in general, to ensure that the results obtained are relevant to the application under consideration.

Annex A
(informative)

Determining the stress relaxation acceleration factor for dry heat test conditions

A common approach to determine the acceleration factor for stress relaxation tests is the use of the Larson-Miller relationship. The Larson-Miller relationship is derived from the Arrhenius life relationship which is a model used to estimate the effects of various temperature dependant degradation mechanisms, including stress relaxation.

The Arrhenius life relationship formula is:

$$t = A \exp[E / (kT)]$$

Using this relationship for stress relaxation:

- t is time in hours to reach a specified level of stress relaxation;
- A is a constant specific to the metal involved;
- E is the excitation energy specific to the metal involved;
- k is Boltzmann's constant;
- T is the absolute Kelvin temperature the part is exposed to.

The Larson-Miller relationship derived from the Arrhenius life relationship is:

$$LM = T\,[C + \log(t)]$$

Where:

- LM is the Larson-Miller Parameter;
- C is a material constant (it is equal to the negative natural logarithm of the constant A from the Arrhenius relationship).

For a given material and degradation mechanism which is modelled by the Arrhenius life relationship, any combination of time and temperature exposure producing a specified value for the Larson-Miller parameter will produce the same level of degradation. Therefore, given a specified lifetime at a specified operating temperature and with the material constant C known, the LM parameter for a contact in the specified application can be calculated. Any temperature life test to produce the same stress relaxation in the part shall then have a combination of time and temperature which will produce the same LM value. This then allows the acceleration factor for the test to be determined as follows:

$$LM_o = T_o\,[C + \log(t_o)]$$

Where:

- LM_o is the LM parameter for the application conditions;
- T_o is the absolute Kelvin temperature of the application;
- t_o is the lifetime in hours at the application operating temperature.

$$LM_t = T_t\,[C + \log(t_t)]$$

Where:

- LM_t is the LM parameter for the test conditions;
- T_t is the absolute Kelvin temperature of the test exposure;
- t_t is the test exposure time in hours.

As noted previously, for the test to duplicate the stress relaxation expected in actual application, the LM values of the application and the test shall be equal. Thus:

$$LM_o = LM_t$$

$$T_o\,[C + \log(t_o)] = T_t\,[C + \log(t_t)]$$

Based on this, the relationship of test time, t_t, to operating lifetime, t_o, is:

$$t_t = 10\text{\textasciicircum}\{[(T_o / T_t)\,(C + \log(t_o))] - C\}$$

This formula thus shows there is a non-linear relationship between test time and operating time for a given combination of operating and test temperatures. Thus the acceleration factor, defined as t_o / t_l, will vary as the operating time to be simulated changes. This is also true if the test temperature is changed.

Annex B
(informative)

Using extreme value distributions to estimate reliability for multiple position connectors

As discussed in 7.2, the position of a contact in a multiple position connector may affect its response to various environmental, mechanical, and electrical stresses. Therefore, within an individual connector, measurements such as resistance, temperature change due to applied current, etc., for individual contacts cannot be assumed to represent measurements taken from a homogenous population of contacts even though the contacts are identical from a manufacturing perspective. For example, consider a connector consisting of four rows each with 4 contacts arranged as illustrated in Figure B.1.

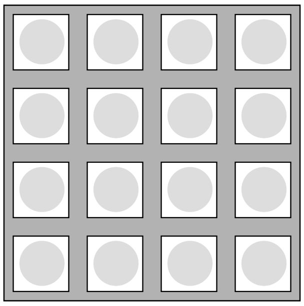

Figure B.1 – Contact arrangement in a square 16 pole connector

If all the contacts were energized simultaneously with the same level of current it would be expected that the four contacts in the centre positions would exhibit the highest increase in temperature as their ability to dissipate heat is restricted on all sides by both the greater distance between them and the outside connector wall and by each being surrounded by eight other contacts also generating heat. The four corner contacts would be expected to have the lowest temperature increase as they can readily dissipate heat directly to the environment through two contact walls and are influenced by heating of only three neighbouring contacts. The other eight contacts would be expected to have temperature increases between those of the centre contacts as they can dissipate heat directly to the environment on only one side and are surrounded by five other contacts generating heat.

Given such positional effects in this example, the temperature increases seen in all sixteen contacts do not represent a single population. Instead there are potentially three distinct populations. Ultimately, the reliability of the connector will be dominated by the performance of those contacts with the most extreme behaviour. Therefore a subgroup of data made up of only the highest or lowest measured value from each connector should be used to estimate the connector reliability. Whether the highest or lowest values are used depends on whether failure occurs due to a performance measure exceeding some criterion (e.g. maximum allowed resistance) or failure occurs due to a performance measure being less than some desired value (e.g. minimum required unmating force). As noted in 7.2, since the data used in estimating connector reliability will be only the highest or lowest values from each connector, they are typically best modelled by either a smallest or largest extreme value distribution.

An example of the use of a largest extreme value distribution for estimating connector reliability is provided using the following data which was randomly generated using a largest extreme value distribution with a location factor of 5 and a scale factor of 2.

2,802, 3,209, 4,043, 4,376, 5,752, 6,917, 7,002, 7,097, 9,639, 10,319

Assume these data represent the highest change in resistance values for each of ten multi-position connectors. Given these data a question which may be asked is “will the connector provide a minimum reliability of 99,9 % given a maximum allowed lifetime change in resistance of 20 mΩ?" Stated another way, the question is "will fewer than 1 connector in 1 000 contain a contact with a change in resistance greater than 20 mΩ at the end of the lifetime simulated by the reliability test program?"

In the following chart these (Figure B.2) data are plotted assuming a fit to a largest extreme value distribution.

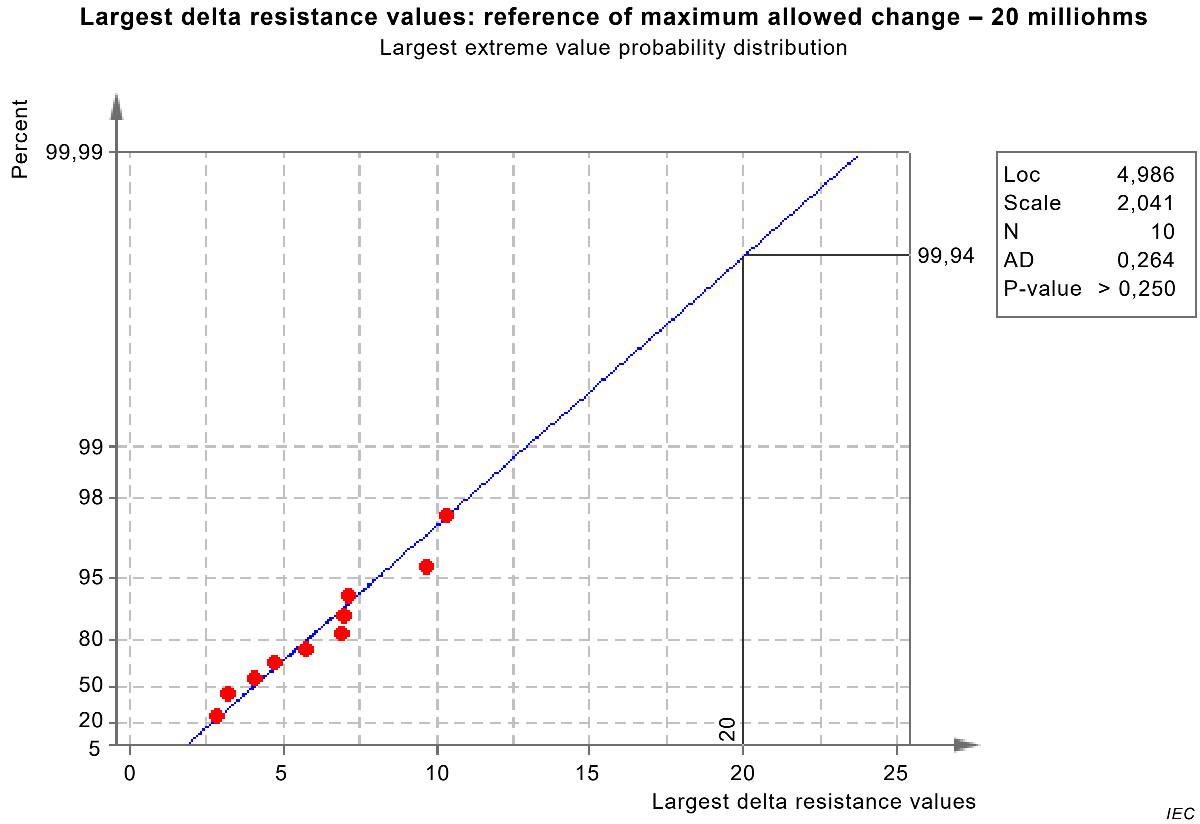

Figure B.2 – Largest ΔR values: reference of maximum allowed change – 20 mΩ

The best estimate for the reliability at a failure criterion of 20 mΩ is 99,94 %. In other words, for every 10 000 connectors used in the intended application, it is estimated that 6 will fail, i.e. contain at least one contact with a change in resistance greater than 20 mΩ, before the end of life. This is greater than the required reliability of 99,9 %.

However, statistical uncertainty in the estimate shall be considered. Given the small though, for connector testing, typical sample size of 10 data points, the uncertainty is relatively large. The chart below (Figure B.3) is similar to that above, but the uncertainty in the actual change in resistance values for a given reliability level is represented by the two outer lines.

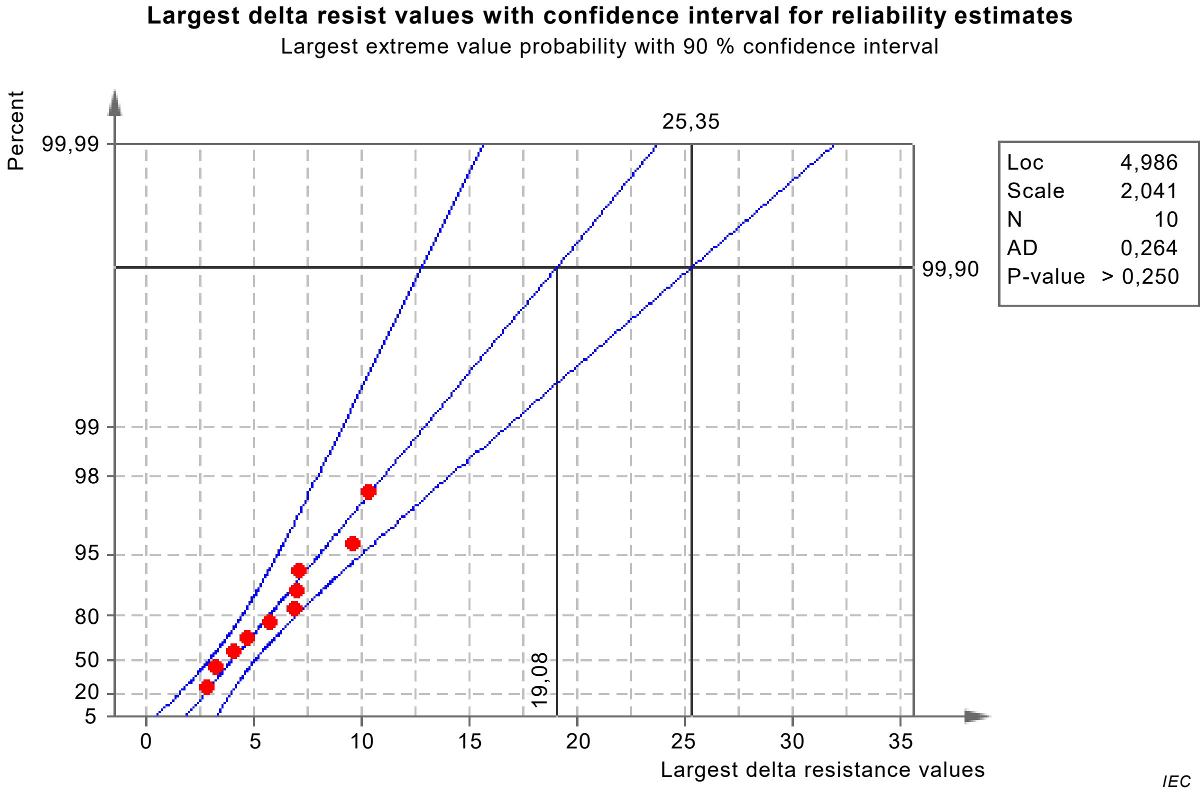

Figure B.3 – Largest ΔR values with confidence interval for reliability estimates – Largest extreme value probability with 90 % confidence interval – Sample size = 10

While the centre line indicates the best estimate for change in resistance at a given reliability level, the outer lines indicate a confidence interval, i.e. a range of delta resistance values, which has some stated probability (90 % in this example) of containing the true 99,9 % reliability value. For the data used in this example, the best estimate for 99,9 % reliability is a failure criterion allowing a maximum change in resistance of 19,08 mΩ. However, there is a 90 % probability that the true value for an allowed maximum change in resistance compatible with 99,9 % reliability is between the points where the 99,9 % reference line intersects the 90 % lower and upper confidence interval boundaries. This range is from 12,81 (not shown on the chart) to 25,35 mΩ. There is a 5 % probability that the true value is less than 12,81 mΩ and a 5 % probability that the true value is greater than 25,35 mΩ.

In most cases the concern is with either the upper or lower confidence boundary. In this case, since failure is a result of exceeding a stated change in resistance value, the concern is with the upper boundary. Thus it can be stated that given the example data analyzed, at a 95 % level of confidence, the product will achieve 99,9 % reliability given a failure criterion of a maximum change in resistance of 25,35 mΩ. The 95 % level of confidence results from the fact that, as stated above, there is a 5 % probability the true 99,9 % reliability value is greater than 25,35 mΩ. Analysis of the data in this example would not support an estimate of 99,9 % reliability with 95 % confidence at the originally stated failure criterion of 20 mΩ maximum change in resistance. Further analysis, not shown here, would show that there would be just 60 % confidence of achieving 99,9 % reliability given a failure criterion of 20 mΩ maximum change in resistance.

Note that one concern when using only the most extreme value for contacts from each connector to make reliability estimates is that the sample size used will be small. It will be equal to the number of connectors tested. Using small sample sizes limits the precision of the resulting reliability estimates, thus the confidence intervals which result may be relatively large as was seen in this example. Consider the same data set used in the previous example but in which the test program used only five connectors as opposed to ten. The following five values were chosen randomly from the original set of ten and then analyzed using a largest extreme value distribution to fit the data , see Figure B.4.

3,209, 4,376, 7,097, 9,639, 10,319

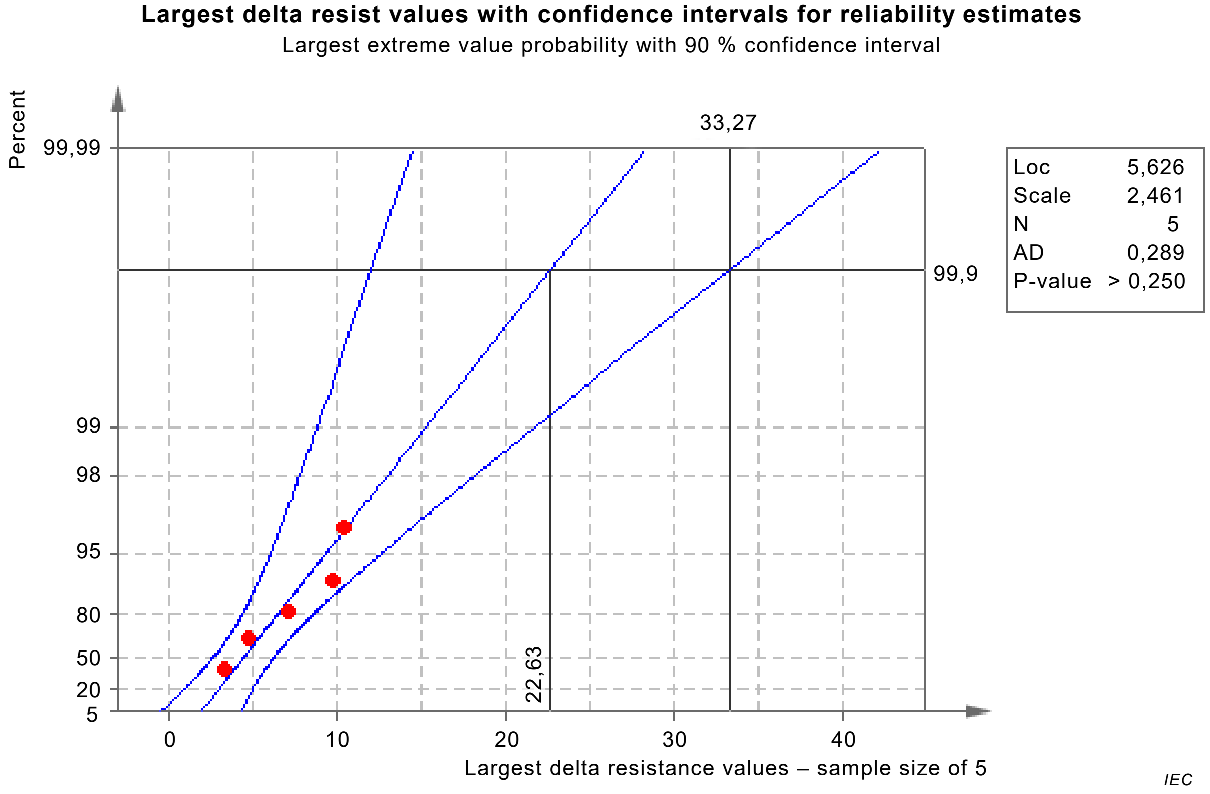

Figure B.4 – Largest ΔR values with confidence interval for reliability estimates – Largest extreme value probability with 90 % confidence interval – Sample size = 5

With this reduced data set the 90 % confidence interval at the 99,9 percentile is now 11,98 to 33,27 and thus larger than the range 12,81 to 25,35 mΩ based on the original full data set of ten values. Of particular note is the increase in the upper limit estimate which increased from 25,35 mΩ with a sample size of ten to 33,27 mΩ with a sample size of five. Conversely, it could also be stated that increasing from a sample size from five to ten led to an improvement in the precision of the estimate of the confidence interval leading to a reduction in the estimated upper limit estimate from a value of 33,27 to one of 25,35 mΩ.

An example of using a larger sample size of 20 is provided below. The data set below includes the original ten values but has been expanded to include ten additional values generated randomly for a largest extreme value distribution with the same parameters as the original data set.

2,619, 2,801, 3,209, 4,036, 4,042, 4,088, 4,168, 4,674, 4,736, 5,591, 5,752, 6,917, 7,002, 7,097, 8,095, 8,663, 8,677, 9,639, 10,319, 11,064

A probability plot for this data fitted to a largest extreme value distribution is shown in Figure B.5.

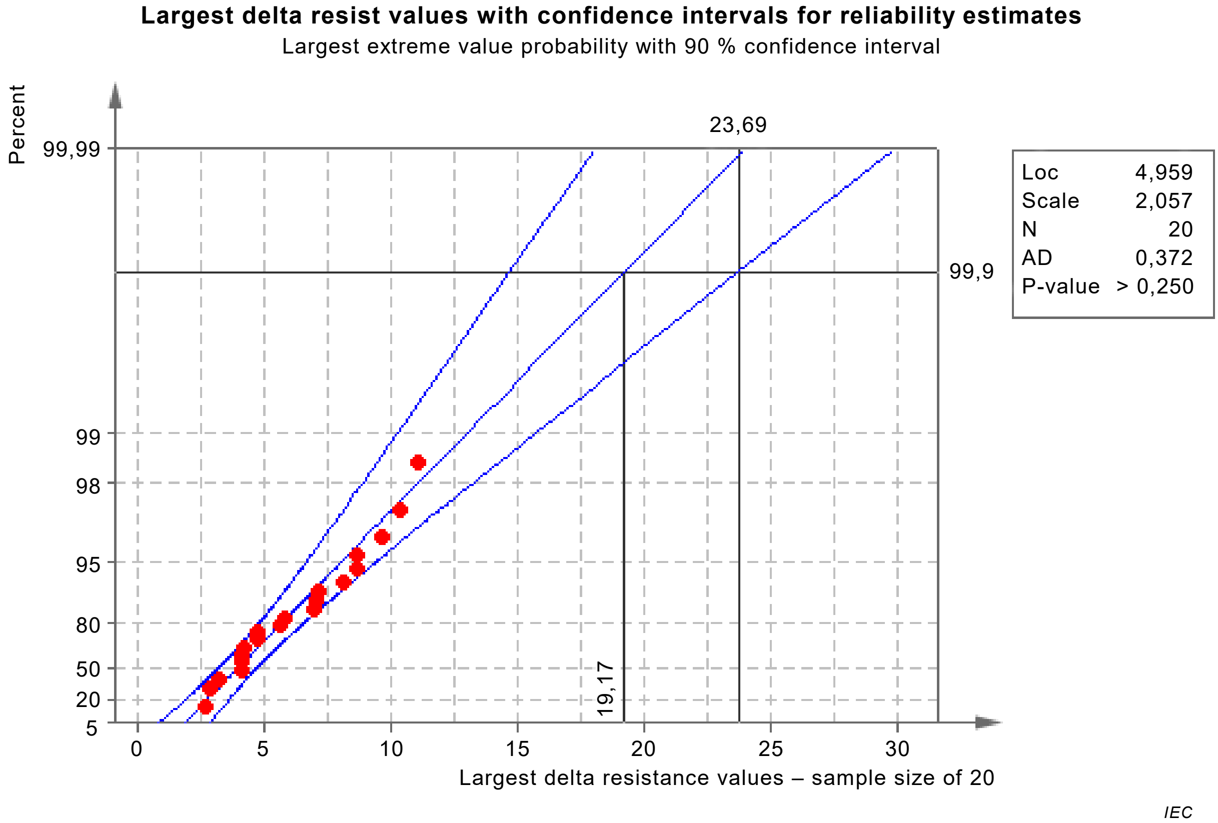

Figure B.5 – Largest ΔR values with confidence interval for reliability estimates – Largest extreme value probability with 90 % confidence interval – Sample size = 20

With this increased sample size of 20, the 90 % confidence interval at the 99,9 percentile is now 14,64 to 23,69, which is smaller than the range 12,81 to 25,35 mΩ based on the original data set of ten values. Increasing the sample size further would in general be expected to further reduce the size of the confidence interval.

As with any statistical estimate based on fitting a distribution to sample data, caution should be used in extrapolating values outside the range of the data. The statistical uncertainty (assuming the model is correct) in the answer should be calculated, and the engineering uncertainty (because the model might not be correct) should be estimated by any reasonable method available, such as by comparing results from parametric and non-parametric (distribution-free) analyses.

The primary purpose of the preceding examples is to demonstrate the use of extreme value distributions using the largest (as in this example) or smallest value for the contacts in each connector tested. Multiple examples were provided to illustrate the effect of sample size on the precision of the estimate of the confidence interval. Since the use of extreme value distributions to fit the reliability test data will use only a single (largest or smallest as appropriate) value for each connector tested, sample size will be equal to the number of connectors tested. Therefore, in order to achieve sufficient precision in the reliability estimate to avoid conservative assessments which may reject designs which are, in fact, acceptable, testing a relatively large number of connectors may be required. However, in contrast to test programs which use multiple groups of connectors each tested to a single dominant stress, the connector reliability test protocol defined in this document uses a single group of connectors subjected to multiple types of stress. Therefore, the total number of connectors required for a reliability test program using the protocol defined in this document and analyzed using an extreme value distribution, as appropriate, may be similar to that required for test programs using multiple groups of connectors each subjected to a different type of stress.

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Useful Contacts

Customer Services
Tel: +44 345 086 9001
Email (orders): orders@bsigroup.com
Email (enquiries): cservices@bsigroup.com

Subscriptions
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Email: subscriptions@bsigroup.com

Knowledge Centre
Tel: +44 20 8996 7004
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BSI Group Headquarters

389 Chiswick High Road London W4 4AL UK

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