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TECHNICAL SPECIFICATION

Process management for avionics – Defining and performing highly accelerated tests in aerospace systems – Application guide

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PROCESS MANAGEMENT FOR AVIONICS – DEFINING AND PERFORMING HIGHLY ACCELERATED TESTS IN AEROSPACE SYSTEMS – APPLICATION GUIDE

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 62500, which is a technical specification, has been prepared by IEC technical committee 107: Process management for avionics.

This technical specification cancels and replaces IEC/PAS 62500 published in 2006. This first edition constitutes a technical revision.

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

Enquiry draft	Report on voting
107/79/DTS	107/90/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 publication 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 maintenance result date indicated on the IEC web site 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- withdrawn,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.

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

In an increasingly harsh economic context (tighter performance requirements, shorter development cycles, reduced cost of ownership, etc.), it is essential to ensure product maturity rapidly and, in any case, by the time of commissioning.

It is with a view to remedying shortcomings in traditional development methods that "highly accelerated" tests have been developed. The main underlying principle behind this new type of test strategy is as follows: rather than reasoning in terms of conformity with a specification and simply performing conventional tests, it is on the contrary attempted to push the product to its limits by applying environmental stresses and/or stimuli of levels higher than the specification. The aim is thus to take full advantage of current technologies, by eliminating defects which generate potential failures, as of the first prototypes.

A well-conducted accelerated test process should, in a relatively short time, lead to a significant increase in the robustness of a product, as early as the initial prototypes stage at the beginning of the development phase, thus accelerating early maturity of this product. Furthermore, identification of the margins available on a "mature" product helps to design and size its future environmental stress screening profile more accurately, by increasing the severity of the loadings applied to just what is needed, leading to a particularly significant boost in the efficiency of this environmental stress screening process.

PROCESS MANAGEMENT FOR AVIONICS – DEFINING AND PERFORMING HIGHLY ACCELERATED TESTS IN AEROSPACE SYSTEMS – APPLICATION GUIDE

1 Scope

This technical specification specifies the targets assigned to highly accelerated tests, their basic principles, their scope of application and their implementation procedures. It is primarily intended for programme managers, designers, test managers, and RAMS experts to facilitate the draft of the specification and execution of highly accelerated tests. This guide is applicable to all programmes and is of primary interest to the industrial firms in charge of designing, developing and producing equipment built for these programmes, and also their customers who, in drafting contractual clauses, may require that their suppliers implement highly accelerated tests.

NOTE This technical specification applies to all types of equipment used in systems developed in these programmes, whatever their nature (electronic, electromechanical, mechanical, electro-hydraulic, electro-pneumatic, etc.) and whatever their size, from "low-level" subassemblies (PCBs, mechanical assemblies, connectors, etc.), up to system level groups of equipment.

2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

NOTE Most of the terminology used in this technical specification conforms to that used in Recommendation RG.Aéro 000 27. For the other terms, it relies on those used in other documents, such as ET 99.04 (see Bibliography).

2.1
step stressing
gradual step-wise increase in the level of stress applied to a product

2.2
hard failure
failure which does not disappear on returning to a lower stress level and which can only be eliminated by repair

2.3
soft failure
failure appearing after a certain given stress level, which disappears when the stress falls back below this level

2.4
extrinsic defect
fault or weakness inherent in the design of a product or its manufacturing processes and the elimination of which, presumed to be economically feasible, leads to an improvement in its operating and/or destruction margins

NOTE This type of defect, which is always the result of a deviation from standard best practices, is not by definition related to the intrinsic limit imposed by the technologies used.

2.5
intrinsic defect
defect related to the component design, materials, processing, assembly or packaging and provoked under circumstances within the component's design specifications

2.6
latent defect
defect which originally exists in the equipment but has not yet been precipitated and is thus as yet undetectable by conventional performance checks on this equipment

2.7
patent defect
defect in a component which, after being precipitated, has become detectable by conventional performance checks

NOTE A patent defect thus stems from a latent defect which has evolved following application of appropriate stresses (e.g. temperature, vibrations, etc.) and which thus becomes detectable by a performance check.

2.8
environmental stress screening
ESS
set of production process tasks consisting in applying to the equipment concerned, within the limits permitted by its design, particular environmental stresses in order – during manufacturing – to reveal and eliminate the largest possible number of extrinsic defects which, in all probability, would have appeared once utilisation had begun (early life failures)

2.9
accelerated test
test, the aim of which is to predict the behaviour and/or lifetime of a product in its operational conditions of use, by subjecting it to stresses harsher than the values expected during its lifespan profile

NOTE Contrary to highly accelerated testing, a "conventional" accelerated test (time/stress exchange) always relies on one or more analytical lifetime and damage models.

2.10
highly accelerated test
test during which the product or some of its component parts are subjected to environmental and/or operating stresses that are increased progressively to values far in excess of the specified values, up to the operating and/or destruction limits of the product

NOTE The rise in exposure time or number of cycles, whether or not associated with a combination of certain stresses raised to values close to or equal to the specification (or stresses whose nature is not specified) may meet the same targets as those of the highly accelerated tests, as defined in this technical specification.

2.11
reliability
ability of a product to perform a required function, in given conditions, for a given time interval

NOTE This characteristic is generally expressed by a probability.

2.12
destruction limit
level of stress above which the product will suffer irreversible damage and will no longer be in conformity with nominal performance once the stress level is returned to below the specified value (notion of irreversibility)

2.13
operating limit
stress level above which the product no longer functions nominally. When the stress is returned to below this level, product performance returns to nominal (notion of reversibility)

2.14
fundamental limit
intrinsic limit determined by the technology of a product or particular component, with respect to a given stress (temperature, vibration, electrical voltage, etc.). This limit, whether or not destructive, is an absolute barrier and cannot therefore be attributed to a extrinsic defect

EXAMPLE: Melting temperature of a plastic, maximum junction temperature of a semiconductor, yield strength of a material, etc.

2.15
operating margin
for a given stress, difference between the operating limit and the specification

2.16
destruct margin
for a given stress, difference between the destruct limit and the specification

2.17
maturity
attainment of a product status for which its functional and operational performance can be considered stabilised with respect to the specifications

NOTE Maturity is the result of a gradual process of eliminating extrinsic defects still present in the product and the associated processes. This process is called maturing.

2.18
precipitation
transformation, using appropriate stresses, of a latent defect (not yet detectable) into a patent defect (detectable)

2.19
robustness
property of a product indicating reduced sensitivity of its performance to changes in the environmental stresses to which it is subjected, to component variation and to drifts in its manufacturing processes

NOTE Robustness to a large extent is the result of action taken to obtain sufficient operating margins while at the same time reducing all forms of variability.

2.20
reliability, availability, maintainability, safety
RAMS
range of capabilities of a product enabling it to achieve specified functional performance, at the required time, for the required duration, without damage to itself or its environment

2.21
failure modes and effects analysis
FMEA
qualitative method of reliability analysis which involves the study of the fault modes which can exist in every sub-item of the item and the determination of the effects of each fault mode on other sub-items of the item and on the required functions of the item

3 Acronyms

- **CDR:** Critical Design Review.
- **FMEA:** Failure Modes and Effects Analysis.
- **EMC:** Electromagnetic Compatibility.
- **ESS:** Environmental Stress Screening.

- **FRACAS:** Failure Reporting and Corrective Action System.
- **HAT:** Highly Accelerated Test
- **MTBF:** Mean Time Between Failures.
- **PCB:** Printed Circuit Board.
- **PDR:** Preliminary Design Review.
- **PRA:** Preliminary Risk Analysis.
- **RAMS:** Reliability, Availability, Maintainability, Safety.
- **RS:** Requirements Specification.
- **RTV:** Rapid Temperature Variation.
- **TTM:** Time To Market.

4 Highly accelerated test goals and principles

4.1 General characteristics

A highly accelerated test is a test in which the product or some of its component parts are subjected to environmental and/or operating stresses which are gradually raised to values in excess of the specified values, until the product operating and/or destruction limits are reached.

The primary purpose of highly accelerated tests is to contribute to:

– improving the robustness of the product, by eliminating the weaknesses inherent in the product design and/or processes, and in the technologies used;
– obtaining products that are mature as of the first production article;
– improving the reliability and lifespan of the product in service;
– reducing development times and costs;
– specifying optimal environmental stress screening.

Attaining these goals involves:

– detecting extrinsic defects as early as possible (so that they can be corrected), as these defects are inherent in design errors or insufficient control of the manufacturing processes,
– exploration of the operating limits, once extrinsic defects have been eliminated so that, whenever applicable, they can be pushed back through new design choices, when the margins in relation to the specified operating range appear inadequate.

Instead of reasoning in terms of conformity with the specification, which is a poor way of reflecting the product's real lifespan profile, it is on the contrary attempted to push the product to breaking point (often up to failure), using environmental stresses or various stimuli at levels far in excess of the specifications, in order to reveal, identify, then correct the extrinsic defects still present. This implies on the one hand exploration of the available margins, and on the other, improving these margins through appropriate action on the design of the product itself or its manufacturing processes (see Annex D).

Owing to the adopted definition for the highly accelerated test, the following characteristics of this type of highly accelerated test can be identified:

– **A highly accelerated test is a proactive type of test:** it is here understood that a highly accelerated test should be considered as a tool to support the design of the product and its processes and that it normally leads to engineering activities aimed at understanding the failure mechanisms observed, in order to provide the corrections felt to be economically feasible and which will enable them to be eliminated or at least delay their evolution. The highly accelerated test is "proactive" in that it encourages these engineering actions at the earliest stage in development.

– **A highly accelerated test is not a conformity test:** through the desire to explore the margins and expand them if necessary, the highly accelerated test looks above all to reveal the product defects which generate failures when working beyond the specifications. It is therefore the opposite of a conformity test, which simply aims to ensure that the product's performance is correct when it is subjected to the specific operating and environmental conditions.
– **A highly accelerated test should not be confused with an ordinary margins verification test**: a margins verification test in fact simply aims to ensure that product performance remains correct when the stress values are raised to predetermined values above the specified values, whatever the initially adopted margin. Consequently, the margins verification test consists in practice in applying an extra coefficient to certain specified stresses (referred to as the "regulation coefficient" in certain mechanical professions). It is similar to a conformity test, even if it deals with performance conformity in operating conditions which are outside the specified range. The highly accelerated test, for its part, establishes operating and/or destruction margins for the product.
– **A highly accelerated test should not be confused with a "conventional" accelerated lifespan test**: the purpose of an accelerated lifespan test is in fact to predict the evolution of the behaviour of a product in its operational conditions of use, by subjecting it to stresses that are harsher than the values expected during its lifespan profile. To do this, the accelerated test relies on analytical product failure mode acceleration models, which is not the case with the highly accelerated test.
– **A highly accelerated test cannot produce reliability measures:** as the highly accelerated test works outside the specified domains, the analytical acceleration models can no longer apply to the domains explored. Furthermore, it is very hard to involve the "time" factor given the very short duration of the test. The result is that as things currently stand, the highly accelerated test cannot be used to estimate product reliability or lifetime characteristics in the specified conditions of use.

Annex A specifies the characteristics of a highly accelerated test versus a growth, validation and reliability qualification test.

4.2 General principles of highly accelerated tests

As a design tool, the highly accelerated test aims – through application of stresses going beyond the specification or simply not specified – to stimulate all the weak points in the product design during development and in its manufacturing processes. Revealing these weak points is thus an opportunity to improve the product or processes more quickly than with a traditional approach, leading to an expansion of the operating margins and thus greater reliability.

It is important to understand that in a highly accelerated test, the stresses applied are chosen so as to actively stimulate the defects and weak points of the product and its processes, and are not therefore designed to simulate the conditions of use of the product during its lifespan profile. These stresses are applied either alone or combined, well past the values expected during the lifespan of the product, until they reach the fundamental intrinsic limit set by the technology. This implies gradually eliminating the various barriers preventing this limit from being reached and which are due to the existence of any weak points still present (extrinsic defects). An essential goal of the highly accelerated test is precisely to reveal the existence of these extrinsic defects, even when they lead to a malfunction of the product used beyond its qualification conditions.

Among the reasons, which justify the desire to correct extrinsic defects, which only trigger malfunctions in out-of-specification product operating conditions, the following could be mentioned:

– the experience built up by companies that use highly accelerated tests shows that most malfunctions detected during these tests end up being detected in the field, if the extrinsic defects revealed by these tests are not eliminated;

– there is often a considerable gap between the specification conditions and the actual conditions of use of a product, in particular if there is a wide variety of a product usage. Consequently, certain lifespan profile situations, sometimes very short, require the product to operate in severity conditions far beyond the specified coverage;

– experience shows that extrinsic defects can often be easily located and can be eliminated or attenuated both easily and economically (e.g.: insufficient component size, inadequately tightened screw, components mounted on vibrating parts of a PCB, PCB inadequately secured in a unit subject to vibration, weakness of a mechanical link, etc.).

Owing to its damaging nature, the principle of the highly accelerated test is thus a cultural sea-change in relation to the traditional approach, the main aim of which is to ensure the conformity of product performance within the specified conditions. As shown in Figure 1, the aim is now no longer simply to show that the product is in conformity, but to prove that exploration has been conducted beyond the specified frontier, in order to clean the product of obstacles limiting its potential robustness, that corresponding to the intrinsic limit set by the technology.

NOTE It is important to note that performing a highly accelerated test should not lead to over-sizing. The ultimate purpose of the highly accelerated test is to track down and eliminate extrinsic defects, those which by their very principle are the result of non-compliance with or ignorance of the state of the art rules of good practice (in design and manufacture). These actions are therefore dedicated to eliminating extrinsic defects, contributing to improving the operating margins and obtaining potential margins. Generally speaking, one does not attempt to push back the fundamental limits of the components and/or materials, which would call into question the design choices (product and/or processes), entailing significant additional investment and time.

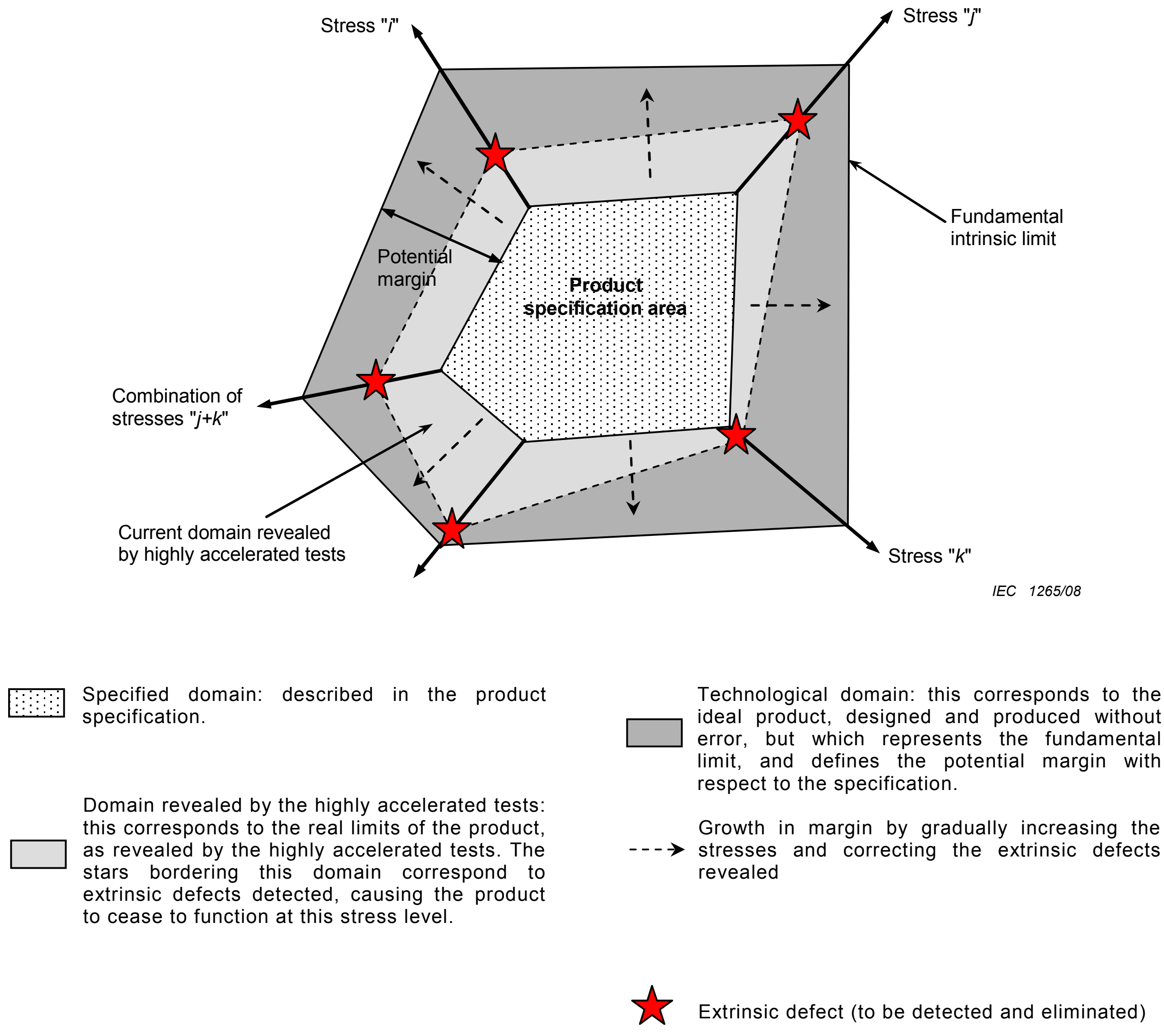


Figure 1 – Exploration of margins using a highly accelerated test

4.3 Example of the limitations of highly accelerated tests

Despite its efficiency and speed, the highly accelerated test method does, nevertheless, have its limitations, and these may, in certain cases, require it to be supplemented by prior specific testing or security checking of product components.

In practice, and independently of the parameters that highly accelerated tests do not address by their very nature (such as ESDs, sealing, etc.), they provide relatively little information about the robustness of products that change over time as a result of internal physical-chemical reactions.

Take, for example, the issue of electromigration in ceramic capacitors:

This effect causes capacitors ultimately to fail as a result of short-circuiting, which may take 2 weeks or 2 years to occur, depending on the design of the product, the manufacturing process and the conditions under which it is used.

Highly accelerated testing of a new product cannot always reveal this type of fault, because at the time of testing, the ceramic capacitor complies fully with its specification and these tests only marginally accelerate the latent electromigration effect.

In this example, prior “batch reliability” security checking of the capacitors supplied would considerably reduce the risk involved. Such prior reliability checking could involve specific humidity/temperature testing of ceramic capacitors, using tests that it may be impossible to apply to the finished product.

On the basis of this example, it is the feedback of experience that will enable manufacturers to decide whether the highly accelerated tests they have installed in their development and mass production processes are sufficient. If not, they should design, evaluate and implement additional filters to achieve the desired degree of robustness.

5 Industrial technical domains covered by highly accelerated tests

The highly accelerated tests apply to all industrial domains.

From the technical viewpoint, highly accelerated tests are appropriate both to electrical and electromechanical equipment and to primarily mechanical components.

In the first case, that of electronic or electromechanical systems, they often consist in applying temperature, vibration and electrical stimuli stresses.

In the second case, the mechanical case, they relate directly to the robustness characteristic well-known to mechanics and which itself relies on the "safety coefficient" concept. Thus, in a purely mechanical context, a static highly accelerated test can consist in subjecting a component or assembly to a rising static stress until, for example, the part deforms or breaks. A dynamic highly accelerated test can consist in subjecting the component or assembly to repeated stress cycles (traction/compression cycles, repeated shocks, etc.) to generate cumulative damage once again leading to deformation or breakage. In this latter case, the highly accelerated nature can apply to various types of criteria: the stress level, the number of cycles, the length of the loadings, the combination of stresses, and so on.

In short, highly accelerated tests can apply to all equipment categories, provided that the most pertinent stresses (mechanical, climatic, electrical, etc.) are used with respect to the expected failure modes on this equipment.

6 Highly accelerated tests in the lifecycle and associated assembly levels

To ensure optimum efficiency, the highly accelerated tests should be integrated as far upstream as possible into the product lifecycle, as of the program feasibility phase, at the time the initial design choices are being made.

During the definition phase, the highly accelerated tests can be implemented on test vehicles to validate the technological choices and/or processes, and then on the first mock-ups or prototypes once available, down to basic subassembly level (board, module, etc.), if the level of testability so allows. The purpose of these first highly accelerated tests is to reveal and correct the design weaknesses. As the development cycle progresses, more advanced highly accelerated tests linked to the degree of complexity of the current levels of assembly, are envisaged. Their goals are: to identify operating margins, to estimate the degree of maturity of the product and/or its manufacturing processes.

There are four advantages in beginning the highly accelerated tests at a low level of assembly, as soon as testability makes it possible:

– corrections are easy to make;

- it is often easier to stimulate low-level assemblies, by applying high stresses, than a complete system;
- defect monitoring is all the easier, the less complex the level of assembly of the entity tested;
- it is possible to work on homogeneous technologies.

For each phase in a highly accelerated test, the number of examples under test will depend on the nature of the highly accelerated tests planned (analysis of a design parameter, validation of operating margins, identification of inadequacies in the manufacturing processes, etc.) and on the economic context.

The main goals of the highly accelerated tests at each of the various steps in the lifecycle are mentioned below.

a) Feasibility

Feasibility corresponds to a technical and industrial analysis with regard to the specified targets. At this stage, a product design orientation file is produced, and risks are examined, in order to eliminate unacceptable risks and draw up a plan of action (to be taken into account as of the definition phase). At this point, the highly accelerated tests to be performed during the definition phase are scheduled.

b) Definition (preliminary design)

After the feasibility analysis and the preliminary risks have been identified, the highly accelerated tests help to ratify the product configuration used as the reference for development launch. When performed on basic sub-assemblies or on an existing product, they contribute to validating a design mode or a technological choice, to clearing risks related to the initial design choices, to requesting additional definition work, to proposing plans of action for the subsequent phases.

c) Development

At the beginning of the development phase, the highly accelerated tests performed on low-level assembly prototypes enable inadequacies to be highlighted and corrected in terms of the electrical, mechanical and sometimes software design.

However, when no functional performance is yet measurable, this becomes a limitation of the highly accelerated tests at this level of assembly. In this case, the highly accelerated tests process can only be initiated at higher levels of assembly.

As the development phase progresses, other prototypes corresponding to more complex levels of assembly become available: sets of interconnected boards, unit components in a system, assembly of mechanical parts, etc. A cycle of highly accelerated tests can be performed at this level on one or more examples, in order to reveal insufficient operating margins of the new assemblies thus created. The quantity and nature of these tests also depend on technological innovations employed and the persistence of the risks, on the checks needed to prepare for running qualification, control of the series production resources, and the need for preparing the environmental stress screening profile applicable to industrialisation and production.

Subject to feasibility, when the first examples of the complete product are available (component or system), in a configuration representative of the production item, a new cycle of highly accelerated tests, tailored to this configuration, can again be run, in order to:

- identify insufficient margins on the interconnections and modules,
- highlight weak points in the manufacturing and assembly processes,

according to the representativeness of the sample of the examples chosen.

Furthermore, the highly accelerated tests facilitate verification and validation stages in the design cycle.

d) Qualification and industrialisation

The highly accelerated tests performed during the previous step contribute to the decision taken during the testability review which determines whether the product is able to undergo qualification and acts as the starting point for defining the profiles to be applied in the environmental stress screening or burn-in program. The product configuration is frozen.

e) Production

During the production phase, periodic highly accelerated tests may be considered on samples, in order to assess/check variability of processes, procured parts, etc.. A process risk analysis has to be performed previously as a trigger to determine the need of highly accelerated tests (HAT) during this phase.

f) Commissioning

Not applicable.

g) Operation

In the operation phase, highly accelerated tests may be used during investigations into confirmed or revealed drifts (modification of certain components, change in suppliers, etc.) through experience feedback or during evolution of design.

7 Planning and management of highly accelerated tests

7.1 General

The highly accelerated tests constitute

- a major development activity, facilitating in particular verification and validation stages, in the same way as the qualification tests;
- an activity involving many program representatives (design, industrialisation, production) whose work should be harmonised by a coordinator, guaranteeing correct performance of the tests and their successful completion;
- a demanding activity in terms of human resources, equipment and tests.

In this respect, and in the same way as the qualification tests, this activity should be planned in the upstream phases of the program, and should then be closely monitored during implementation.

The aim of this clause is to state, independently of the techniques employed and as described in the next clause, the steps that should be taken when planning the tests and when performing them.

In addition, setting up a highly accelerated tests procedure is one of the steps taken to deal with the risk of belated product maturity and lack of robustness. The aims of the approach are set in the light of these risks, at the same time as the requirements concerning the product. The level of residual risk after performance of the highly accelerated tests should therefore be analysed, as should the stresses linked to this approach.

7.2 Validation and verification

Highly accelerated tests are central to the validation of specifications and the verification of final products.

The objectives of this approach are:

- to ensure that the requirements imposed by technical specifications will meet the needs of the final user (validation);
- to ensure that the intermediate products and final product will comply with their specifications, particularly those concerned with maturity and robustness (verification).

To achieve these two objectives, the validation and verification approach requires the implementation of key activities, such as:

– accepting the requirements imposed by technical specifications and validating the user needs and constraints supplied by the customer;
– validating the hypotheses on which product specifications are based, i.e. the assurance that the specifications are sufficiently appropriate, correct and complete and that the final product will comply with the explicit and implicit needs of users;
– verifying that intermediate products and the final product comply with their individual specifications.

Highly accelerated tests use the results obtained from the first two activities as preliminary product risk analyses and form an integral part of validation and verification.

7.3 Planning of highly accelerated tests

When planning the program (feasibility phase), it is recommended that the highly accelerated tests be taken into account by drawing up a specific plan dedicated to maturity. This test plan should include the following:

– definition of the targets to be attained, based on the product risks analysis and the specified requirements;
– definition of the work linked to these tests (tasks flowchart): the implementation methodology for the highly accelerated tests describes the process in more detail in the following paragraphs, which enables the tasks to be defined. In general, the following heavily influence the scope of the work:
  • identification of the components and/or sub-assemblies that will be included in the highly accelerated tests approach, and their number;
  • definition of the tests conducted and the associated resources for each element;
  • the criteria determining continuation and/or cessation of tests, the process being iterative;
  • the scope of the corrective actions anticipated on the basis of the results;
– the planned resources: running the tests will require the involvement of various participants (designer, industrialisation and manufacturing managers, etc.), in an iterative process. It is essential to take account of this additional activity and ensure optimum coordination between these various resources;
– the necessary means (tools and test benches, supervisory resources, etc.);
– number and nature of examples subjected to testing;
– the planned recourse to outside resources (specialist laboratories, etc.). If, as is usually the case, the tests cannot be performed with in-house test resources, outside test organisations have to be utilised. The conditions in which these organisations work should be defined and planned, so that they can be brought into the process and contribute their own expertise;
– the planned work durations enable a schedule to be drawn up.

All these elements will enable budgets to be allocated to this activity. They are generally fairly large, but the following should be noted:

– on the one hand, that these budgets vary widely according to the scale of the test campaign;
– on the other, that these budgets should be compared with the cost of non-quality and "non-maturity" (MTBF not achieved, belated re-design, retrofits, etc.) and are generally far lower, owing to the early detection of defects (see Clause 11).

7.4 Management of highly accelerated tests

Once the highly accelerated tests have been scheduled, the coordinator in charge of the tests should ensure that this phase runs smoothly, in particular:

– availability of resources (testing, design, industrialisation, production, specialists, etc.);
– training of the various parties involved;
– smooth running of the failure analysis and root causes search process. The highly accelerated tests approach is in fact only effective if associated with an incident processing logic validated beforehand;
– smooth running of the test series, taking into account contingencies;
– identification of all incidents;
– taking of decisions concerning corrective action;
– compliance with schedules: significant drift may lead to the process being cut short (whether this is desired or not), or not being conducted with the necessary stringency, in particular with regard to the incident processing logic, making the process unproductive, or even counter-productive;
– building on results acquired throughout the test campaign (experience feedback);
– budget monitoring: the pertinence of the approach should also be demonstrated on the basis of economic criteria, the direct and induced expenses involved in the approach should be identified and checked, so that they can be compared with the cost of failing to correct the failures;
– integration of these tests into the company culture.

Running the "highly accelerated tests" activity should be formalised in a management chart or other specific summary document allowing effective coordination.

8 General methodology for implementing highly accelerated tests

8.1 Structure of the approach

To be effective and profitable, the highly accelerated tests should rely on a structured methodology clearly understood by the various participants.

It is above all essential to understand the behaviour of the product, the expected risks and its reaction to the stresses to be applied to it, in order to be able to rule on the failures found and decide on what action to be taken. This knowledge is necessary so as to establish the expected spectrum of failures and their mechanisms, in order to determine which of them it will or will not be possible to activate. It will then be possible to determine the most appropriate stresses for this activation so that they can be applied in the highly accelerated tests, subject to the necessary resources being available.

The complete approach can thus be broken down into five main sequences:

– analysis of sensitive points;
– selection of the applicable stresses;
– preparation of the test plan;
– performance of tests;
– analysis of the results and implementation of corrective action.

This approach leads to definition of tests customised for each product and each company.

8.2 Analysis of product sensitive points

A key step in running a highly accelerated tests approach is to determine beforehand the sensitive points of the product, that is, those in which operational failures are most to be expected.

Identifying points felt to be "sensitive" should reinforce the pertinence of the highly accelerated tests given that it is attempted to use stresses the nature of which should allow effective stimulation of the failure mechanisms associated with these sensitive points.

Identification of the sensitive points, in addition to risk analyses and product and process FMEAs, above all involves a technical analysis of:

– the product definition file: parts lists, technical specifications, specification, etc.;
– definition of the means of production and associated processes;
– characterisation of the product lifespan profile, in particular the nature of the function stresses (e.g.: on/off cycles, mechanical stresses, electrical stresses) and environmental stresses (heat, cold, humidity, vibrations, etc.) to which the product will normally be subjected in its future conditions of use, along with the quantification in terms of levels, transition variation, frequency or duration of the main loads and stresses identified.

In the case of low-innovation products (i.e.: proven technologies, environments and operating profiles), best use (capitalisation) should be made of the *accumulated in-house experience* acquired on products using similar technologies. This capitalisation leads to pertinent information being provided on:

– the most significant loadings generated on the product;
– the origin of observed malfunctions;
– the associated failure mechanisms;
– the environmental agents or relevant loadings, the existence of which favoured the observed malfunctions.

The available information generally comes from:

– operation of similar products in the field;
– various similar product (and/or process) development and qualification tests;
– experiment plans oriented towards the design choices (design of the product and/or processes) and the results of which can indicate that some of the characteristics observed, for example linked to the materials, technologies, attachments, mounting or assembly techniques, are particularly sensitive to the values adopted for certain environmental stresses or usual loadings;
– highly accelerated tests which have been performed on similar products.

The information provided by this data base can also be obtained or supplemented by expert knowledge (e.g. components experts, materials experts, quality method, etc.) depending on the technologies concerned.

In the case of highly innovative products (for example: new technologies, new processes, little proven or unproven environments and utilisation profiles), it is necessary to be able to rely on:

– a preliminary risk analysis (PRA) which in particular takes account of the existence of external sources of hazards;
– FMEAs: these analyses, which include those from the suppliers, identify the characteristics of the product and/or processes (innovative technologies, specific circuits, new mounting or assembly techniques, electrical or mechanical components, etc.) in which certain failure modes can, according to the experts, have a high probability of occurrence in light of the induced commercial or safety consequences;

– simulations (electrical, thermal, mechanical, stress-damage modelling, physics of failure, etc.) achieved during development.

In particular, any conceptual or technological innovation should be considered as likely to present a high risk of failure, whenever no experience feedback or sufficiently well documented test results are available. It is therefore possible to rank all these potentially critical elements according to:

– estimated probability of failure,

– uncertainty around these probabilities,

– the consequences of these failures.

Therefore, whatever their nature, taking account of and performing detailed analysis of these various information sources (forecast analysis, feedback from the field, test results) should lead to identification of the product zones which are in principle most vulnerable, the associated failure mechanisms and the nature of the environmental stresses and usual loadings most likely to stimulate these mechanisms.

8.3 Selection of applicable stresses

The stresses and loadings adopted in the highly accelerated tests will be those which stimulate as effectively as possible the failure modes characteristic of the points of the product felt to be vulnerable. These latter were identified using the available information sources, according to the criteria defined in the previous paragraph.

An effective method is to draw up a table (see Annex B), in which the columns correspond to the various sensitive points identified and the rows to clearly defined loadings (e.g.: random vibrations, heat, cold, thermal variation, on/off cycles, etc.). There is naturally no point in listing all the foreseeable loadings. One therefore concentrates on identifying the following:

– those loadings which are in principle the most "aggressive" (owing to their nature or their level) and which were identified when characterising the product lifespan profile;

– the environmental stresses which, even if absent or only rarely present in the normal conditions of use of the product, are believed to have a significant impact on activation of the expected failure mechanisms on the sensitive points of the product.

Using this table, with or without weighting, the loadings and environmental stresses which in principle have a high potential for stimulating the predominant failure mechanisms associated with the identified sensitive points of the product will be highlighted. Organising and using this table is naturally the responsibility of the highly accelerated tests steering group.

It will be ensured that the loadings and stresses chosen for the highly accelerated tests are such that as many sensitive points as possible of the product can be stimulated, even if this means using loadings which are absent from or rarely present in the conditions of use of the product. It should not be forgotten that the key idea here is to "stimulate", and not to "simulate".

Moreover, the analysis data, which contributed to selecting the stresses previously identified, cannot claim to be exhaustive, and certain stresses that have proven their effectiveness in stimulating the usual failure mechanisms on similar products can be applied systematically.

In practice, the tests will be designed to allow optimum application of each loading appropriate to the sensitive points identified. In certain cases, this can lead the assembly under test to be split into various sub-assemblies to which it will be simpler to apply the required loading(s) while preserving the ability of measurement (e.g.: digital electronic circuits, attaching parts, fragile assemblies, etc.).

Finally, one should remember that simultaneous application of particular stresses can lead to a synergy of effects improving the activation of certain defect mechanisms and thus reducing the number and cost of the tests. This may, in particular, be the case of vibration cycles combined with thermal cycles, or on/off cycles combined with temperature. When this type of case is identified in the analysis of the efficiency table, it may be preferable to run a test simultaneously combining the stresses in question, if resources and economic considerations so allow. Analysing the causes of the defects observed may, however, prove more difficult than in the case of an individual stress test and thus, it may be a more delicate affair to determine appropriate corrective action.

NOTE The product may contain a very weak component that will mask the other weaknesses of the product. It is then essential to strengthen the weak element by circumventing this element (e.g. LCD insulation from temperature) before launching a campaign of highly accelerated tests. Furthermore, some mechanisms may be activated by several types of stresses. It is then possible to choose the most effective stress or that which is simplest to use.

8.4 Producing a test plan

The test plan should be written up in a document containing all information and recommendations necessary for performing the tests and correctly interpreting the results.

It should contain at least the following:

a) **A concise description of the product under test:** this product description, both physical and functional (dimensions, weight, utilisation, etc.) ensures that the tests are feasible and checks that the resources employed are compatible with the product to be tested.

b) **The list of identified potential risks:**

   – those included in the test program;

   – those not included because of the limitations set by budgets, resources or deadlines;

   – those impacting safety of product, environment and operators during testing.

c) **The size of the sample:**

   Statistics may serve as an input for determining the size of the sample to be tested. In practice, this size is justified by the need to replace (spare parts or repair) faulty products or sub-assemblies in order to enable the test campaign to continue. So, if the price of the product so allows, it is always interesting to be able to test several products under stress. This improves the representativeness of the failure/stress combination.

d) **The list of standards or documents** relevant to the product, its operation and its lifespan profile: this list gives information vital to the estimating of the stresses and implementation of the tests to be applied, and could avoid reproducing tests already performed.

e) **The list of tools or resources** needed for performing the tests, including the number of products to be tested and their allocation during the tests. This list describes:

   – the means used to apply the stresses;

   – the size of the product sample and the product allocation;

   – the elements needed for the products to operate;

   – the test tools;

   – the stress measuring tools.

f) **The interface between test resources and products and the modifications to be made to the products:** it is in fact essential to ensure that the stresses are correctly applied to the product. To do this, it may be necessary to adapt the product mechanical structure or protections, for example:

   – make openings to allow air to pass;

   – remove covers;

   – inhibit thermal protection systems;

   – ensure that vibrations are transmitted to all components;

   – use an interface or plate to arrange the equipment and protect it from damage by stress other than that linked to the applied stresses.

Appropriate tooling may, if necessary, be developed to allow optimum transfer of the applied stress from the test resource to the product.

g) **Product instrumentation:** in order to control the levels of stresses employed, the product when subjected to the highly accelerated tests should be instrumented. This instrumentation (thermocouples, accelerometers, strain gauges, etc.) will also allow effective measurement of the product's response to the stresses. Installation of this instrumentation will be defined on the basis of the risk analyses and simulation results and will be targeted at the most sensitive components.

h) **Definition of the good operating state:** definition of the good operating state of the product should allow an unambiguous declaration of whether or not its operation is altered by applying the stress. Definition of the good operating state and the "faulty" state thus enables the test to be run in real time.

i) **Description of the tests allowing permanent checking of the good operation of the product under test:** functional monitoring of the product which is as complete as possible is necessary during the highly accelerated tests in order to record any malfunction along with the stress levels which revealed it.

   This functional monitoring should be taken into account as of the beginning of the product design phase. It may potentially be reused in production phases such as environmental stress screening, if necessary.

   In operation, it is often necessary to include a built-in test in a product. For certain products, cessation of operation is enough to detect all failures, however, this is not the case with complex products or products which comprise secondary or monitoring functions. It is then essential to develop or adapt an additional test tool usable during the highly accelerated tests.

j) **Description of the test sequence:** each test should be covered by a specific paragraph stipulating:

   – the type of stress or combination of stresses;
   – the order in which the stresses are applied;
   – the step sequences;
   – the levels of stresses at the various steps;
   – the duration of each step;
   – the actions to be performed at each step.

   Particular attention should be given to the test sequencing, given the choices of stresses and the identified failure mechanisms.

   The procedure for the highly accelerated tests is to increase the amplitude of the stress in steps up to the failure levels. This same principle is applied to defining the order of stresses on the products. One therefore begins with the type of stress least damaging to the product. In electronics, for example, operation at high temperature is generally more damaging than at low temperature, so the tests will be run at low temperature before being run at high temperature.

   The combined stress tests are performed after the unit stress test. The fact of applying several stresses in combination may be useful because the reaction of the product may not be the same as with a succession of single stresses. In the combined tests, care will be taken to apply a first stress at its maximum no-failure level previously determined, and the other stress will be incrementally applied until failure or up to the level reached with the single stress. This way of sequencing the highly accelerated tests guarantees against the problems arising with analysing several failures which occurred simultaneously and allows a search for the root causes of a failure on a single stress/failure pairing at a time.

To conclude, the test sequence should not be random, but should follow a loading logic which always moves up to the next higher stress level and moves from the simple to the complex.

The network of tests thus described constitutes a guide and it should be possible to adapt it according to the product's reactions to the stresses applied.

8.5 Performing tests

Performing the highly accelerated tests involves the following two sequences:

- test preparation;
- actual performance of the tests.

Test preparation comprises:

- conditioning the sample for correct exposure to the stresses (attachments, energy flow, etc.) and validation thereof,
- instrumentation: attachment of sensors and probes,
- positioning on the mounting interface in the test resource,
- check on operation of product and test tools in the test resource environment.

It may also be necessary to run a "dummy" test outside the test resource, to check that the instrumentation or the modifications made to the product have not altered its operation.

The stresses are applied to the product with the *step stressing* method, using the guide described in the test plan. In principle, the starting value of each stress is close to the specification value if any, and this value is increased in successive increments, the level of which is stipulated in the test specification. When a malfunction occurs at a given value of the applied stress, the test is temporarily interrupted to analyse the cause of the malfunction. Participation of the designer is essential for a quick evaluation of the importance of the malfunction detected. After an initial analysis and to resume the test as quickly as possible, it is useful to have several specimens of the product to be tested, or at least to have spares to repair the product or replace the item concerned. It is therefore possible to set aside the item which caused the failure and conduct a more extensive search for causes later (see next paragraph).

Once the product has been repaired or a circumvention solution found (example: specific protection for a component, removal of component, etc.), the test continues, once again stepping up the stress level, until the fundamental limit is reached. This means that one does not simply look for the first product-operating limit, but one aims to go further, possibly up to the destruction limit, insofar as the test resources so allow.

Throughout the tests, and in order to be easily analysable, the information collected should comprise at least the following:

- the complete test program: stress levels, application times,
- the malfunctions observed and the corresponding measured and applied stress values,
- the presumed origin of the failures or the origin determined by evaluation,
- the repairs made, the components replaced and/or the bypass methods employed,
- the identification of the operating limit and the destruction limit.

This information may be grouped in "test sheet" format and will be incorporated into the test report.

Performance of the tests uses the currently applicable incident processing logic (FRACAS).

At the end of the tests, the product is removed from the test facility, taking care to prevent damage to the instrumentation or the product, for it may be necessary either to resume testing in the same conditions, or to run additional tests, should the data collected be insufficient for successful analysis of the failure.

8.6 Analysis of test results, corrective action and resumption of testing

Concerning the analysis of test results and processing of the events that occurred during the tests, two main approaches are possible (the right choice for the product should be described in the test plan):

a) The tests are run in full according to the program in the plan. After these tests, a summary report and samples containing defects is obtained. Findings are drawn up and the search is conducted for the root causes of the defects.

b) The tests are interrupted as soon as a fault occurs, in order to identify the root cause. A failure diagnosis is made. There are then two possible cases:

   - diagnosis is easy (manufacturing process not followed, obvious weakness of a component, etc), repairs are made and the same product resumes the test in progress,
   - an in-depth failure analysis is needed:
     - the defect is identified. The possible corrective actions are applied and the test is restarted with the repaired and provisionally corrected original product, or another product (temporarily corrected) as applicable;
     - the origin of the defect is not formally identified. The product is left as is, repaired or replaced and the test resumes. The failure analysis is conducted in parallel. The potential corrective action is taken into account further to this analysis.

The final goal of the failure analysis is thus to determine the "root causes" of all the failures identified, in order to define and implement the necessary corrective action, insofar as these causes actually correspond to a clearly identifiable extrinsic defect. As applicable, this corrective action can range from simple replacement of an unsuitable component to relocation of a PCB or a change to a manufacturing process.

Once defined, these corrective actions are applied to one or more examples of the product. Depending on program constraints (schedule, financing, availability of test resources, etc.) a further series of highly accelerated tests will be conducted on all or part of the program.

There are two reasons for performing highly accelerated tests after taking corrective action:

– to check that the operating and/or destruction limits of the product have indeed been pushed back;

– to check that the modifications introduced have not generated new problems running contrary to the goals set with regard to the previous limits.

The implementation logic for the highly accelerated tests presented in this subclause is schematically shown in Annex C.

9 Building on and using experience

9.1 General

The experience obtained when running or analysing the results of the highly accelerated tests should be put to good use by:

– creating a database;

– enhancing the company's reference system;

– participating in defining environmental stress screening;

– checking that the product has achieved maturity;

– moving company culture forwards.

9.2 Creating the database

Experience should be capitalised in a database, consistently with the FRACAS, accessible to all professions within the company involved in the design and construction of products, so that each party can draw benefit from it.

It will comprise at least two types of data:

– data concerning how the products behave under stress (final robustness, operating limits, etc.);
– data concerning all failures encountered during the tests and in particular, the nature of the stresses which revealed weak points and the associated failure mechanisms, along with the associated corrective action.

To achieve this, the database contains at least the following data:

– product;
– product family;
– dominant technologies;
– particularities (e.g. technological heterogeneity);
– tests performed;
– types of stresses;
– maximum levels;
– resources used (stresses and test bench);
– results;
– failures observed: symptoms, stresses, root cause, corrective action on the product;
– residual weak points;
– margins obtained.

9.3 Inclusion in the company reference system

As the product was designed and manufactured in accordance with the current reference system, it may be necessary to alter, modify or add to it in the light of the results of the highly accelerated tests. This may, for example, affect:

– the rules and processes for choosing components, materials, etc.;
– the rules and processes for development and design;
– the rules and processes for manufacture, ESS and process qualification.

9.4 Use of results for environmental stress screening

Environmental stress screening (ESS) is an operation applied to products in production to transform latent defects into patent defects detectable by the manufacturer before final acceptance and delivery to the customer. It may be conducted on 100 % of all manufactured products or on a sample in the case of large volumes with process control.

ESS is usually carried out by applying thermal and/or vibration stresses, whose profiles are defined on the basis of experience feedback ("historical" profiles already implemented on similar products).

ESS using combined tests (thermal, mechanical and electrical) can prove far more effective than tests performed sequentially, with this effectiveness depending on the nature of the product, the nature of the latent defects and the resources used.

The fact of having conducted highly accelerated tests on the product during its development gives a clearer picture of its limit (operational and/or destruction) and identifies its weak points. These results should be used to improve the effectiveness of ESS through a logical tightening (choice, severity) of the stresses.

One should also ensure that this ESS is efficient and does not consume usable life of a conforming product, as it should eradicate early failures and may find design and manufacturing process quality issues while not significantly reducing the life of the product.

9.5 Correlation with feedback

In order to check the effectiveness of the highly accelerated tests, it is important to compare the events encountered during the life of the product (production, commissioning, operation, etc.) with the results of the tests performed.

The following cases may occur:

– the defects revealed during the highly accelerated tests and then corrected, no longer appear;

– the defects which appear during operation were seen in the highly accelerated tests and intentionally not dealt with. A case-by-case analysis is required;

– the defects which appear during operation were not seen during the highly accelerated tests. An in-depth analysis of the root causes should be performed, which can lead to a new series of adapted or more pertinent highly accelerated tests.

9.6 Synthesis and impact on company culture

The highly accelerated tests are a specific approach that should be adopted by each company and then refined to take into account its experience of its products.

The usual qualification/validation tests are generally well known and are often covered by standards that one need simply follow to the letter. However, the highly accelerated tests, based on a search for limits rather than a simple verification of parameters, require that those who run them have not only technological knowledge of the product, but also knowledge of all manufacturing and operating processes. It is also necessary to understand how the product behaves faced with the stresses to which it may be subjected throughout its life and how the failure mechanisms develop.

The highly accelerated tests thus induce different attitudes and behaviour within the company than the validation test approach.

Indeed, the improvement plans are no longer produced after complete development of the product, but directly incorporated into the development plan. Their implementation obliges the company to adopt a preventive rather than curative attitude.

10 Customer/supplier relations

10.1 Prime contractor/supplier relations

10.1.1 Responsibilities

The supplier has expertise in the design and production of its products, described in the company's reference system. In this respect, it assumes responsibility for defining, preparing and performing the highly accelerated tests, applicable to its products with the best value for money. However, prime contractors may impose highly accelerated test stresses and levels, to obtain the assurance of a minimum level of robustness. In this case, the prime contractor should provide the information needed to determine the resources and time required for the tests.

Each participant is responsible for the tasks entrusted to him. He is also responsible for correct transfer of data to the lower and higher levels in the tasks organisation chart (see figures in Annex C).

In any case, the supplier remains responsible for assessing the pertinence of the margins obtained after the tests.

10.1.2 Contract procedures

The customer expresses its requirements in the requirements specification (RS), defining its maturity related targets (for example: first-fit removal rate, MTBF following commissioning, etc.), particular requirements concerning the operating profile, potential events affecting the product, and so on.

As regards the highly accelerated tests, the prime contractor may:

- simply formulate general results targets: in which case, the supplier is totally responsible for defining the highly accelerated tests;
- set resource obligations (methodology, types of stresses). In this case, the supplier proposes a preliminary program of highly accelerated tests, defining the timeframe (in accordance with the product development cycle), the way of managing residual risks, potential limits (economic and calendar) on the test and the content of the test report. A preliminary agreement should be obtained from the prime contractor concerning the highly accelerated tests program.

Once product development has been launched, with the agreement of the prime contractor, the program of highly accelerated tests is refined as product design progresses. It should be updated and available before the design reviews (preliminary definition review, critical definition review (CDR)).

In the contract, the following should be well negotiated:

- the list and status of deliverable documents (test programs, test reports, expert assessment reports, etc.);
- the level of technical visibility expected by the prime contractor;
- test iterations necessary for validating the corrective action.

10.1.3 Tests synthesis

Following the tests, a report is produced by the supplier, showing the limitations in relation to the specifications, if any, and including an exhaustive list of malfunctions observed, how they were treated and the corrective action taken.

It is particularly important for the supplier to monitor the formulation and management of residual risks, especially when the test objectives have not been reached (insufficient test resources, etc.). If the prime contractor has accepted the program of highly accelerated tests, any discrepancies should be communicated to it.

NOTE Particular vigilance should be exercised when interpreting test results beyond the specification limits, in particular with respect to a certification authority or legal authority.

10.2 Supplier/test laboratory relations

The in-house or external test laboratory is responsible for performing the highly accelerated tests in accordance with the established program, and contributes its expertise.

Throughout the testing, the designer's support is essential when deciding on whether or not to continue the tests, when determining possible bypass solutions, when determining repair solutions or when developing the test program as applicable.

The test laboratory assists the supplier when defining the test tools.

The test laboratory and the supplier jointly validate the test resources configuration, before the program launch.

The test laboratory records and synthesises all data related to the different test phases (stress, level, duration, measurements, technical events observed, etc.).

Any deviation between the program and the actual tests should be identified and written up in the test report, to ensure the traceability of the conditions in which the tests were performed.

11 Costs and savings

11.1 General

The profitability of the highly accelerated tests lies essentially in the gains obtained by early identification and correction of defects, which easily offset the expenses of conducting these tests. A design defect corrected late on in the product cycle in fact incurs considerable expense:

– either in terms of delay in time to market (TTM),
– or in terms of failures with the customers, retrofits and harm to the brand image.

The economic analysis therefore entails establishing the difference between:

– the costs of product "non-reliability", caused by:
  - losses arising from delay in product time to market,
  - the costs of operational failures,
  - the costs of engineering for recovery of the design after development,
  - the cost of products retrofitting,
  - costs linked to the impaired brand image

  and
– the expenses generated by implementing the highly accelerated tests, chiefly comprising:
  - test engineering,
  - specific test and checking resources,
  - the manpower needed to run the tests,
  - failure analyses,
  - the costs of engineering for recovery of the design during development,
  - damaged and irretrievable products.

The elements to be taken into account when costing these various items, can be detailed as indicated in 11.2 and 11.3.

11.2 "Non-reliability" costs

11.2.1 Cost in delayed time to market

Today, the delay in time to market is without doubt the most penalising element for the product, especially in highly competitive sectors where the technologies evolve rapidly. This is why the time to market (TTM) date has become essential for a project under development.

In principle, the "highly accelerated tests" process is an extra burden on the product development schedule, making it longer. However, experience shows that the forecast TTM date, set when the project is initialised, is almost never met, precisely because of development difficulties or insufficient reliability, which can be avoided by carrying out highly accelerated tests.

By defining a development schedule incorporating a series of highly accelerated tests, a time to market date which is admittedly a little less optimistic, but certainly more realistic and which varies far less, is determined. The time to market date is today far too variable to be able to consider that product development is flawless and that the new technologies are immediately mastered. Highly accelerated tests provide a solution to this problem.

The turnover for a product can in fact be represented by a curve comprising three separate periods:

– production growth, as of market release;
– a stable period of varying length, characteristic of the commercial life of a product;
– a period of decline when other higher-performance products reach the market.

The following Figure 2 comprises two curves. Curve (1) is for an ideal product, reaching the market on time. The total production level then reaches the target set by the sales managers and on which the profitability of the product was based. Curve (2) illustrates a product that is late with respect to market demand.

There are then two possible cases:

a) the product belongs to a captive market and sales will reach the targets, but belatedly. The financial losses only affect the "growth" period and thus the commercial lifespan;
b) the product is on an open market. All market shares not occupied from the outset will be lost for good. The total level of sales will be lower, in direct proportion to the length of the delay. If the delay is too great, market release of the product may even be compromised and the product may not be marketed.

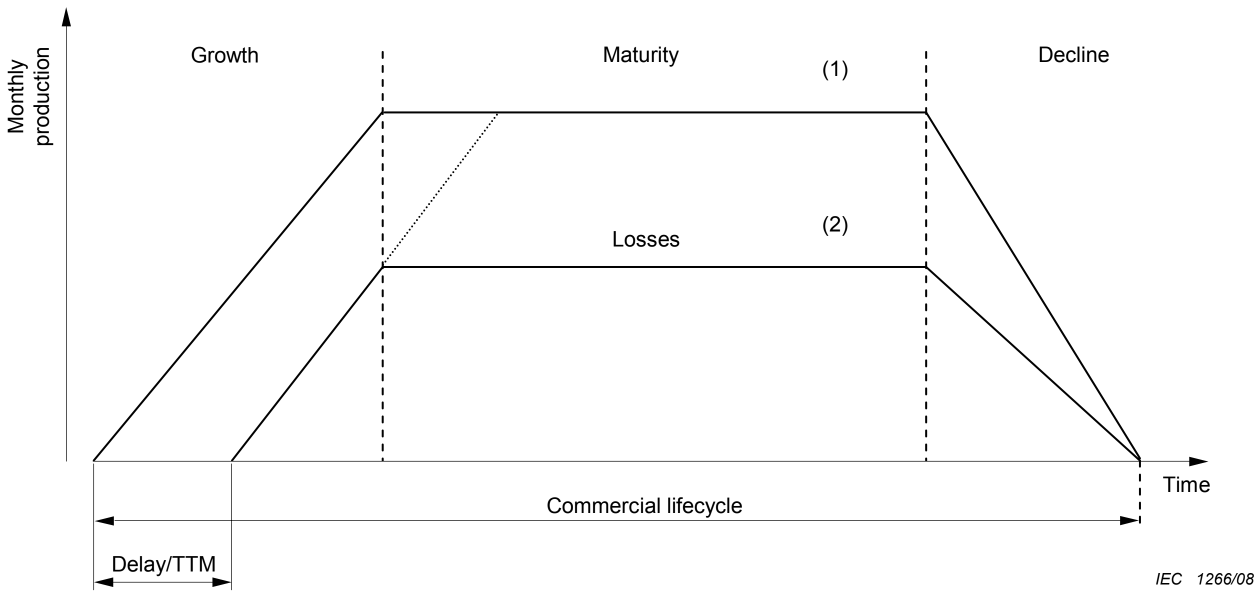


Figure 2 – Financial losses generated by a delay in time to market

11.2.2 Cost of an in-service failure

To determine the cost of an in-service failure, the simplest way is to draw up the scenario involved in repairing the system containing the product, detailing the equipment and labour costs involved in each step, without forgetting the costs specific to spare parts (forecasting, stock compilation and management).

The total cost of an in-service failure generally includes:

– the cost of repairing the replaced part or the price of a new part;
– the cost of managing the logistics centre which handles the spares;
– the rental on parts in stock;
– procurements;
– the time spent by the maintenance personnel;
– etc.

To this cost, affecting the company that makes the product, can be added penalties related to the trading loss of the user.

11.2.3 Cost of a recovery operation

A recovery operation consists in retrieving a part of a system or a complete product containing a defect, in order to repair it. Recovery can be general (throughout the installed base), selective (only on the critical sites or a limited series of products) or simply logistic (on stocks).

The recovery operation is typically indicative of a product on which reliability is not stabilised. The later the defect is identified the higher its cost.

The cost of recovery includes:

– the cost of initial stocks to initialise the cycle;
– the cost of the recovery operations;
– the cost of the logistics put in place for equipment rotations;
– etc.

11.2.4 Impact on brand image

A product whose reliability at the beginning of its life is mediocre is likely to be rapidly discredited in the eyes of the customer. This will have consequences, even when product reliability has been subsequently improved.

Delay in time to market creates a bad commercial climate, prejudicial to the brand image.

A problem with a product has repercussions on the other products in the line, but also on the effectiveness of the company's communication efforts, as brand image is one of the key sales arguments in the activity sector.

The impact on brand image is hard to cost. One can however assume that this is a major factor in aggravating losses.

11.3 Expenses generated by the highly accelerated tests

11.3.1 Engineering upstream of testing

Engineering upstream of the highly accelerated tests includes:

– the search for potential risks liable to affect use of the product. This search, usually based on an existing FMEA, may in fact not generate any extra cost;

– selection of the applicable stresses or determination of the means to be used to excite the potential failure mechanisms;

– preparation and drafting of a test plan which describes how to perform the tests, the equipment used both to apply the stresses and operate/test the product during the tests.

These various activities correspond to a provision of expertise, the scope of which will primarily depend on the complexity of the product.

11.3.2 Test resources used

This involves:

– usual resources (thermal chambers, vibrators, etc.);

– material resources (e.g. thermal chambers with very high RTV, 6-axis vibrators, etc.), which go beyond the bounds of traditional tests, in-house or subcontracting in specialized laboratories;

– dedicated test software;

– dedicated interfaces (e.g. specific jig for bending a PCB) which will have to be built to apply the stresses with maximum efficiency.

11.3.3 Manpower dedicated to highly accelerated tests

This section includes the manpower costs generated by the activities:

– of the various experts who will be running the test;

– of the operators performing the tests (*in-situ* or in the subcontractor laboratory);

– of the designers who are to analyse the failures and make improvements to the product;

– of the laboratories (in-house or external) who will be performing the failure analyses.

11.3.4 The cost of damaged or destroyed products

Equipment pushed to its limits is weakened and cannot therefore be delivered to the customer. This subclause should be considered carefully, in that it depends on the size of the sample subjected to testing. The aim is however, to have a sample that is as large as possible, to be able to:

– keep as many defective products as possible, to maximise the amount of information about failures;

– establish the dispersal of operating and/or destruction limits.

Annex A
(informative)

Comparative characteristics of highly accelerated tests and reliability tests

Table A.1 – Comparative characteristics of highly accelerated tests and reliability tests

	Highly accelerated tests	**Reliability growth tests (RGT)**	**Reliability qualification tests (RQT)**	**Production reliability tests (PRT)**
Program phase	Start of validation / prototype	End of validation / prototype/pre-production	Qualification / pre-production/production	Production
Product status	Any product status in its lifecycle	Product burned-in design defined	Product burned-in design frozen	Product burned-in design frozen
Selection criteria	Recent design Non-proven technology Intended for a new use Manufacturing transfer	Recent design Non-proven technology Intended for a new use	In case of customer requirements	In case of customer requirements
Test duration	2 to 4 weeks, iterations included	> 5 times the forecast MTBF	< 5 times the forecast MTBF	< 5 times the forecast MTBF
Applicable stresses	Choice of stresses resulting from PRA/FMEA Application of stepped stresses Individual and/or combined stresses	Taken from product specification Depending on lifespan profile Individual and/or combined stresses	Taken from product specification Depending on lifespan profile Individual and/or combined stresses	Taken from product specification Depending on lifespan profile Individual and/or combined stresses
Purpose of test	To reveal and correct latent weaknesses To determine the operating and destruction margins	To improve operational reliability To reveal and correct latent weaknesses	To check product conformity with specified target	To check that product quality and reliability are maintained throughout production cycle
Capitalisa-tion on test	Looping with: 1) PRA 2) FMEA 3) Feedback 4) ESS	Looping with: 5) PRA 6) FMEA 7) Feedback 8) Forecast evaluations	Looping with: 9) Feedback 10) Forecast evaluations	Looping with: 11) Feedback 12) Control of manufacturing process

Annex B
(informative)

Example of potential effectiveness table for stresses or loadings according to the nature of the product sensitive point

Table B.1 – Example of potential effectiveness table for stresses or loadings according to the nature of the product sensitive point

Stress or loading	Product sensitive point														
	P1	**P2**	**P3**					**Pi**							**Pn**
Climatic domain															
Heat			X								X				
Cold			X		X									X	
RTV			X		X			X			X			X	
Humidity		X				X		X							
Salt mist					X						X				
Dust	X								X						
Other…															
Mechanical domain															
Random vibrations	X				X						X	X			
Mechanical shocks			X	X											
Bending/twisting						X								X	
Other…															
Electrical domain															
EMC							X			X					
On/off cycles		X					X						X		X
Voltage variations		X		X						X					X
Other…															
Chemical domain															
Organic vapours	X							X	X						
Acid vapours	X					X		X	X					X	
Other…															

NOTE 1 The "X" symbols in the table can easily be replaced by effectiveness marks.

NOTE 2 Pi corresponds to the i^{th} identified sensitive point.

Annex C
(normative)

Highly accelerated tests implementation logic

C.1 General logical flowchart

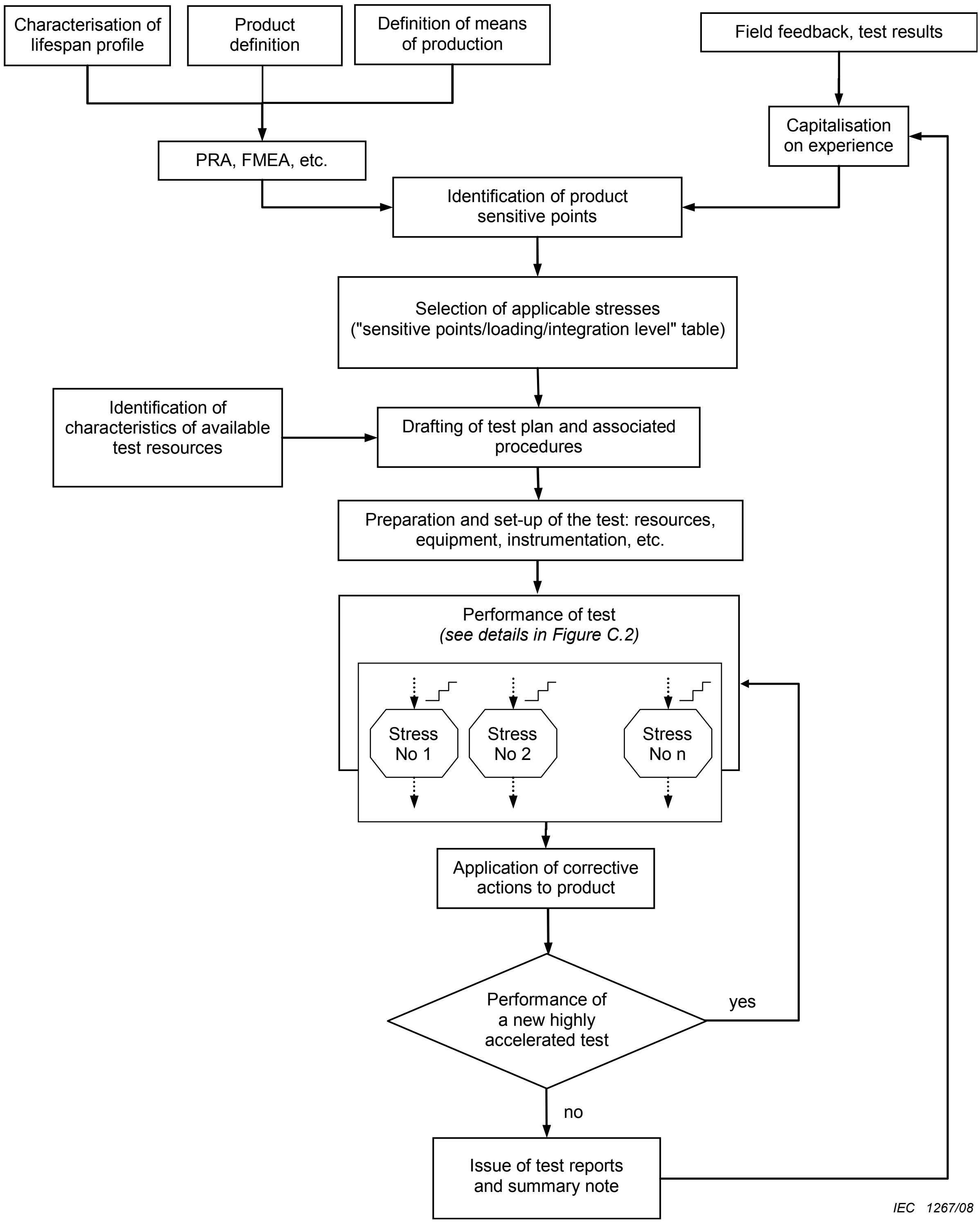


Figure C.1 – General logical flowchart

C.2 Details of test performance

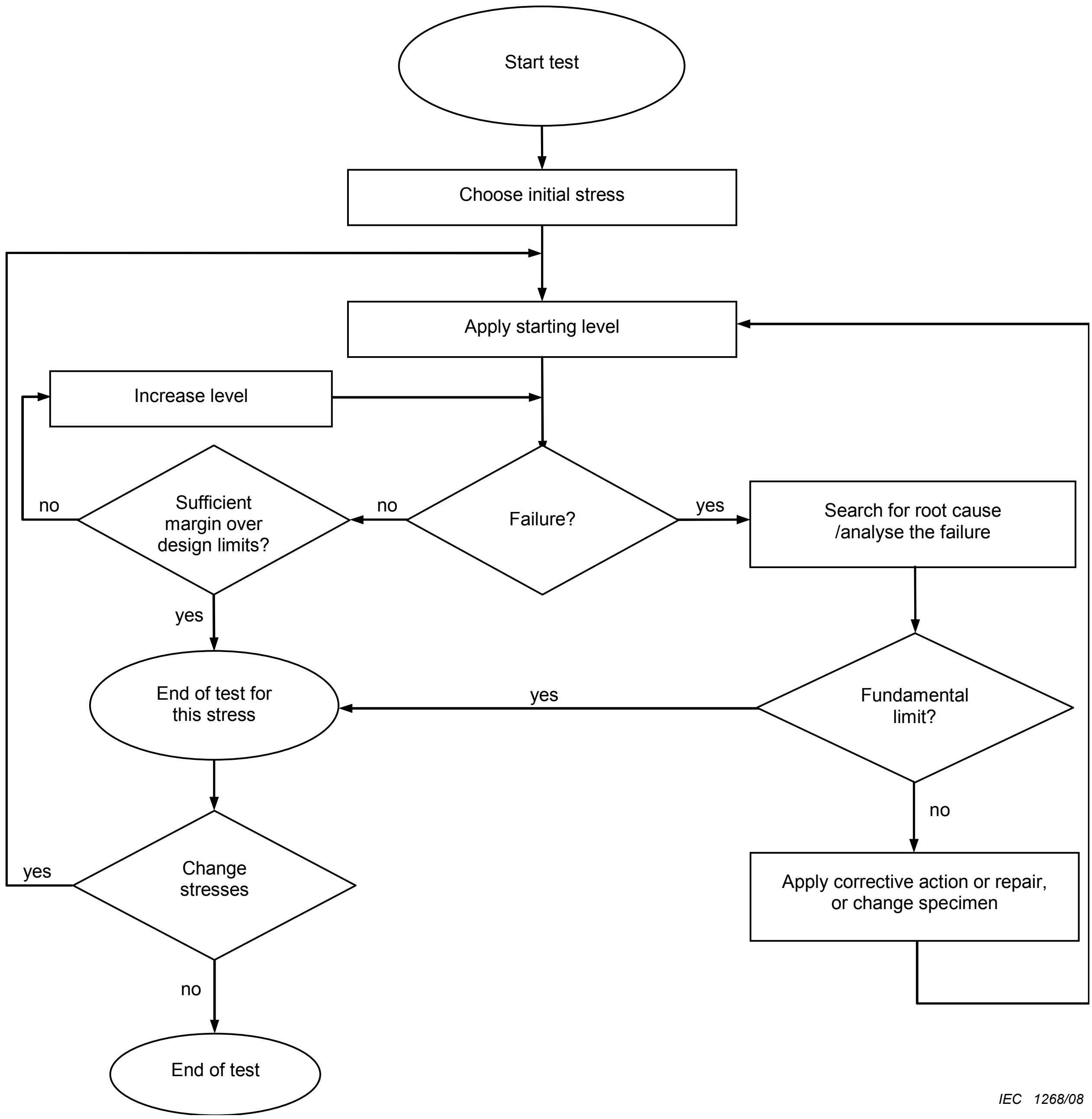


Figure C.2 – Details of test performance

This logic also applies if a test is to be repeated.

Annex D
(informative)

Margin-related statistical considerations – Example: telecommunications circuit boards or board assembly

The concept of margin takes into account the various dispersions related to components and the design and production processes.

This annex gives an example of the margin options open to the designer, over and above the contents of the specification (see Figure D.1).

The extent of dispersion is measured in terms of its standard deviation (σ for an assumedly normal law).

In terms of temperature, some companies have used their experience to establish rules and estimate that the σ is 4 °C.

So, for a dispersion of ± 3 σ, a minimum margin of (2 × 3 × 4) °C = 24 °C will be required in order to ensure that the operating limit will be acceptable for the product in 99,865 % of cases.

Example: for a product whose specifications are – 20 °C, + 50 °C, all those limitations found between – 20 °C – 24 °C = – 44 °C and + 50 °C + 24 °C = + 74 °C should be corrected.

Similarly, with a dispersion of ± 4 σ, the minimum margin required will be 32 °C in order to ensure that the operating limit will be acceptable in 99,997 % of cases.

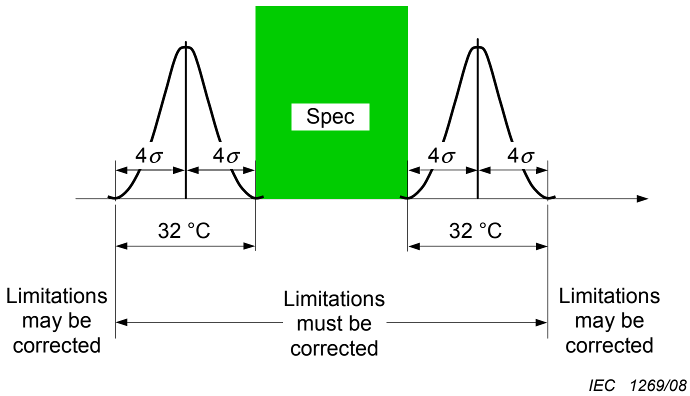
The same approach may be applied to vibration.

On the basis of experience, some companies have found that 20 grms is a good average value and that the σ dispersion is 2 grms.

Where 4 σ is adopted, any limitation observed during highly accelerated testing below 20 grms + (4 × 2) grms = 28 grms should be corrected.

These indicative margin values for temperature (24 °C or 32 °C) and vibration (28 grms) are based on the experience of dispersion gained by particular companies.

They should therefore be adapted to suit individual circumstances.



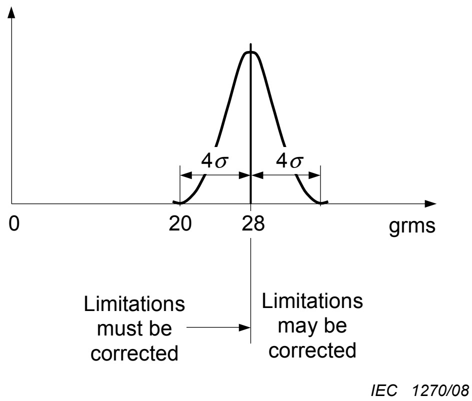


Figure D.1 – Examples of the margin options open to the designer

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1 These documents are available in English at www.bnae.asso.fr.

2 This document is available, in French only, at www.imdr.eu (see first "Activités" then "Documents en vente").

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