Problems in Assessing the Reliability of Electronic Components and Systems by Reliability Testing

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Abstract – **This paper concerns reliability evaluation of electronic devices due reliability tests. Basic groups of tests are described. Some problems in their implementation are observed. A development in this regard is presented and guidelines for further work are outlined.**

Keywords – **Electronic Devices, Reliability, Reliability tests.**

I. INTRODUCTION

Manufacture of electronic devices has two aspects - mining and processing of raw materials on the one hand and on the other - creating a final consumer product. By increasing the reliability as an essential part of quality, the economic efficiency of the devices dramatically increases, thus compensating the lower efficiency of the commodities' conversion process.

Striving to create a competitive production imposes the extension of the classical concept of quality production, which comes down to answer questions related to the processes that follow producing of devices, such as:

- Do devices fail in the early stage of operation?
- Is the *Burn-In* process sufficient?
- Is the failure rate value acceptable in the normal operation lifecycle?
- What adjustments in the design, manufacture, operation and maintenance can lead to higher reliability?

They can be represented three levels of implementation of reliability as a concept [1]:

1. Reliability prediction - at the design stage. Reliability is assessed: - for the design - through parametrical failures; - for the elements - through sudden failure; - for the devices - through failures from defects, caused by production processes.
2. Technical (nominal) reliability – by using the data from testing of first batch samples ("zero" series) under laboratory conditions imitating the real operational once.
3. Operational reliability - according the data from real operation of mass production devices.

For electronic devices such levels are in direct correlation with the main stages of their life-cycle - design, manufacture and operation. Figure 1 shows the sequence of stages and of their constituent phases.

Creating first test samples and test series gives possibility to carry out reliability tests in order to obtain experimental data and more accurately determination of reliability parameters.

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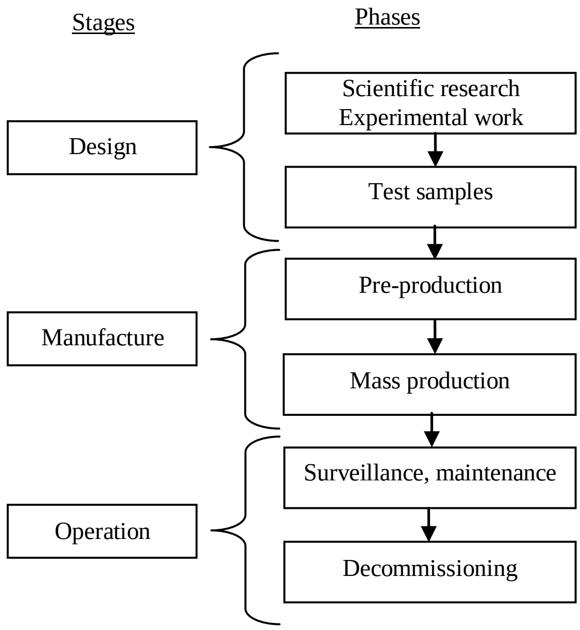

Fig.1. Life-cycle of electronic devices

The manufacturing stage consists of two phases. The first phase, called "pre-production" represents technological preparation and optimization of manufacturing processes, and also the equipment selection. Limited test series of products are produces. During the second phase, "mass production", the devices are produced in their final form, ready for field operation. Large amounts of uniform production are manufactured. It could mean, in present terms, series of several hundred to several million units of production.

Operational stage is the period of real operation of the devices and comprises the largest part of their life-cycle. During this stage the devices reveal their features, including in terms of reliability.

The reliability of electronic products throughout their lifetime is kept at the desired level by technical maintenance, including inspection, failure localization and repair, replacement parts and others. The high cost of maintenance poses questions about the optimality of the implemented procedures. The optimization of maintenance is subject to research by many scientists as Ushakov [2], Benbow and Broom [3], Moubray [4].

After a certain moment a physical and technological obsolescence of products happens. Nowadays, because of accelerated products' development and shortening the duration of the first two stages of the life-cycle the technological obsolescence often overtakes the onset of physical aging.

The assessment of reliability of the products is a procedure of successive stage-followed adjustment of reliability parameters' estimates with regard to construction, technology, manufacturing, operational algorithms, operating rules and conditions, maintenance and repair procedures, and criteria for the occurrence of failures and boundary states.

In recent years, manufacturers achieve a significant improvement of the reliability of manufactured devices. Furthermore, a considerable part of failures are due to reasons not directly related to components and circuits, such as errors or inaccuracies in the manufacturing process, software problems, unsuitable design choices, external overstresses. This sets new issues related to precise determination of the causes of failures and difficulties associated with assessing the reliability parameters of electronic devices in terms of lack of registered failures or limited number of them.

Reliability Tests

Environmental Tests

- Environmental Stress Screening ESS
- Burn-In
- Reliability Demonstration Tests RDT
- Reliability Assessment Tests RAT

Accelerated Tests

- Accelerated Life Tests ALT
- Accelerated Degradation Tests ADT
- Highly Accelerated Life Tests HALT
- Highly Accelerated Stress Screening HASS

Fig.2. Reliability tests summary

II. Reliability testing

A. Summary

Figure 2 presents classification of reliability tests, prepared under the criterion "conditions of the tests." Accordingly, tests can be divided into three groups:

- *Environmental tests* are held in conditions similar or identical to the most common in the real working conditions; they could be performed within normal operating conditions, but close to the border values of the main factors determining normal working conditions;

- *Accelerated tests* are held in conditions beyond the specified normal operating conditions.

In economic terms it is crucial the time needed to collect the necessary information that provides the data for assessing the products' reliability. This is the reason further in the article to be examined in details the third group of the above classification - accelerated tests.

The fast development of electronics in the last decade has imposed a shortening of the time from development to the realization of electronic products. Aiming for evaluating the reliability in short time raises the need to develop sufficiently precise and convenient for practical application test methods, which to ensure for a short time correct assessment of the main indicators of reliability – mean time to failure *MTTF*, failure rate λ, availability R(t), mean time between failure *MTBF*, etc. Under proper planning and precise execution, the accelerated tests provide reliable information to determine the potential mechanisms of occurrence of failures and modeling of the distribution law of failures of electronic products. The application of reliability testing of electronic systems and components in the initial phases of their lives is crucial to meeting the requirements for reliability in the later phases of production. Elsayed [5] describes the process *TAFT* for elimination of design defects in the initial samples by testing, analyzing data collected, removal of registered weaknesses and re-testing. This process is generally represented by the term "Reliability growth".

In many cases, the accelerated tests are the only applicable approach to assessing reliability. They can be used for:

a) reliability assessment electronic products and the quality of materials used;

b) identifying types of failures, their localization in the devices under test (*DUT*) and taking actions to prevent them;

c) electro-thermal training to remove items with hidden defects (*Burn-In*);

d) predicting the performance of the device under real operational conditions and its behavior under extreme load stresses and external impacts.

B. Environmental tests

When stress values are close to the environmental conditions, such tests are named environmental stress screening *ESS*. In *ESS*, all the products are tested with the aim to speed up and find out the hidden defects as earlier as possible in the production cycle, making their removal cost-effectively. Such tests could be combined with systems for measuring and automation control [6], to extend the benefits beyond the usual objectives of each approach.

A special kind of reliability tests represents technological training of electronic products. In the literature it is known as electrothermal training or "*Burn-In*". *MIL-STD*-883 [7], has defined it as "... test performed to monitor or separation of the devices having internal defects or defects caused by deviations in the production process that led to failures dependent on the duration of operation and load." Burn-In provides an interesting opportunity in terms of evaluating the reliability of manufactured electronic devices due to the application a stress (thermal or electrical) on all products. This makes it possible to trace the impact on the devices not only as an originated failure or lack of it, but as changes in certain controlled informative indicators. The use of Burn-in tests in this type of classification would save costs for additional tests. Difficulties could arise due to lower stress levels and shorter duration of Burn-In tests, which limits the range of dispersion of informative indicators for classification, respectively accuracy of the final reliability classification results.

Environmental tests are also used to demonstrate the compliance of the actual assessments of reliability parameters of the devices with the specified once, regarding the requirements - reliability demonstration tests *RDT*. An example of such an approach is represented by Yadav [8]. *RDT* are usually held within normal working conditions of the devices. Similar tests are applied due delivery-and-acceptance procedures – reliability acceptance tests *RAT*. The results of these tests provide information that is used for decision about acceptance or rejection of the series of products of which was formed the tested sample.

C. Accelerated reliability tests

Highly accelerated life tests *HALT* can be performed with two different goals - to define the limits of the operating conditions of tested products, and to express and analyze all possible failures in products. *HALT* in electronic products is carried out by applying stress factors temperature and vibrations and is used most frequently for analyzing problems in the functioning of the circuit boards. Subject to certain restrictions, such tests can be used in modeling of processes in power electrical engineering, such as lightning protection [9]. The same stress factors, but with a smaller stress values are applied in highly accelerated stress screening *HASS*, to confirm the ability of the products to function properly under cyclic loading. The main difference between the two tests is the object of study - *HALT* explore usually test samples and series prior mass production, while during *HASS* are tested samples of the mass production of the devices. *HASS* provide opportunities to 'catch' changes in the quality of the production process.

Devices, in which the aging process is manifested at an earlier stage, are tested by accelerated aging tests *ADT* [10].

The application of accelerated tests is studied and systematized by many scientists as Nelson, in his remarkable work "Accelerated Testing. Statistical Models, Test Plans, and Data Analysis" [11], Ushakov [2] and many others. Many publications and methodologies present the application of accelerated tests in different versions aimed at achieving a sufficiently precise estimates of indicators of reliability [12][13][7][14]. Escobar and Meeker, in an extended report, review many types of accelerated tests in order "to outline some of the main ideas behind the accelerated tests" and to formulate "proposals for potential contributions to which statisticians could help to the development the methods and models of accelerated tests" [15]. In another article Meeker draws attention to the problems associated with the selection, planning and implementation of accelerated tests [16]. The great variety of techniques gives engineers multiple reliability analysis tools through accelerated reliability tests, and their task is to choose the most appropriate in accordance with applied tests and available preliminary information.

D. Test planning

When tests are performed for the first time on certain products, planning is done on the basis of known theories of optimal, best plan and plan with restrictions (compromises) [11]. Prior knowledge, collected due tests on products, similar in functionality or composition, is used to initially determine the range of change in stress factors, the duration of the tests and sample size. However, there is enough uncertainty that makes plans tentative, and may lead to surpluses or shortages of required information. The possibility of further optimization of tests, through dynamic assessment of the results, is not sufficient studied. The results of such optimization can be expressed in additional spending cuts of time and money while keeping the accuracy of the final results within acceptable limits. *IEC* 61649 [17] presents set of requirements for conducting accelerated tests. Many developments in the planning and optimization of accelerated tests are presented in the scientific literature [2][17]. Test parameters usually are determined in advance on the basis of preliminary studies of conducted tests on similar devices, normative documents and optimization procedures. An important characteristic of the tests is a manner of recording the moments of occurrence of failures – exactly or roughly. If there is continuous control, by man or machine, on all tested devices, any failure is recorded at the exact moment of occurrence and there are no errors in assessing the parameters of reliability, caused by uncertainty of timing of failures. The registration of exact times of failure occurrences is difficult to realize, sometimes impossible, especially in data collection during the operation. The information about failures usually does not contain the precise moment and data can be of the following type - censored data (left or right), grouped (interval) data or reported only at the beginning and end of the test duration. It often happens to be handled with different data types in a research. While censored data of different types and exact data are object of a number of studies, the interval data is less common in the science literature.

Recently the accelerated tests are associated with tasks for evaluation of indicators describing various aspects of the reliability of devices. This determines the variety of combinations of types and combinations of stresses applied, ways for stress application and other conditions. The scientific literature describes accelerated tests, applied on electronic products, with different plans and mathematical formalism [18][19][20].

III. Problems of Assessing the Reliability of Electronic Devices over the Different Stages of Their Life Cycle

The products' reliability depends on the decisions taken during the period of design and production. Therefore, it can be concluded that reliability is the property of the product, which is modeled and built into it and requires the investment of considerable resources and time. So considered, the process of „embedding" of reliability outlines many problems. Below are presented only two of them and the ensuing conflicts:

First problem - "materialization" of the term "sufficient reliability" for each particular product.

Second problem - decision of how to achieve the level of "sufficient reliability" in every product manufactured.

First conflict - Time: Growing competition shortens the overall length of all life stages of products: design - testing - production - operation - technological obsolescence - design of completely new product or release of devices with enhanced options. This naturally requires cutting the time spent on reliability testing and analysis of the devices.

Second conflict - Price: The wide variety of products with similar, even identical characteristics requires seeking the solutions that ensure low prices of the output product. This is reflected in the reduction of planned spending on research of reliability.

Wrong decisions lead to losses, resulting not only in unforeseen costs for warranty service, but also in reduced sales and revenue from the negative impact of the customers' dissatisfaction. The effect extends more globally; negatively affect the reputation of the manufacturer, putting question mark over its survival in a highly competitive landscape of electronic products. From the customer's perspective and in a "good" case scenario the insufficient reliability means more periods of inactivity and spending more time and money for maintenance. When it comes to manufacturers, this directly affects their current and prospective revenues. In a "worst" case scenario, however, the consequences can be expressed with the destruction of material facilities, injuries or loss of human lives. Murthy analyzed some aspects of the above cases in a series of publications [21][22][23]. The complex nature of these problems and conflicts does not allow the formulation of a clear decision, and requires operating in an uncertainty in many ways.

IV. CONCLUSIONS AND FUTURE WORK

The problems of dynamically optimization of accelerated tests, aiming to increase the efficiency of tests by using ongoing assessment of their informativeness, are the subject of research by the authors of this publication. Algorithms are examined in Burn-In and accelerated tests [24][25]. The following issues are encountered, which are subject to further work:

1. Insufficient ability to determine the indications of classification of devices after *Burn-In*.
2. Significant complexity and the need arises to establish limits for efficient use – cost/effect.
3. It was reported, during tracing of conducting the accelerated tests, a difficulty in establishing a set of indicators defining the right moment for termination, replacement or continuation of a test. It is obtained a divergence of the chosen indicators goodness-of-fit r^2 and error function *Ej*, therefore it is necessary work to identify additional markers for decision making.

With regard to tests on highly reliable devices and registration of a little failures and interval data, an approach " Interval Weibayes" was proposed [26]. Further work is focused on combination of effective strategies for reliability-oriented maintenance and systems for continuous monitoring, in order to develop an approach for detection of approaching failure conditions, with the limitation of "false alarms".

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