40. EAN
40. MEZINÁRODNÍ KONFERENCE EXPERIMENTÁLNÍ ANALÝZY NAPĚTÍ
40th INTERNATIONAL CONFERENCE EXPERIMENTAL STRESS ANALYSIS
3. – 6. VI. 2002, PRAHA/PRAGUE, CZECH REPUBLIC

# OPTIMISATION OF THE BURN-IN PROCESS

**Radovan Novotný – Josef Bradík**[1]

*The reliability of electronic devices constitutes an important aspect of quality control. Burn-in is an accelerated screening procedure that eliminates infant mortalities early on in the shop before shipping out the devices to the customers. Burn-in is screening premature failure at high temperature and high electrical loading. The design of experiments using sound statistically oriented thinking is an important aspect of the solution of the optimisation of the burn-in process.*

**Keywords: reliability, burn-in, technological process, electronic devices, design of experiment, screening experiment**

## 1 Preface

### *1.1 Burn-in process*

A few products show a decreasing failure rate in the early life and an increasing failure rate in later life. One of the fundamental concepts in reliability is the "Bathtub" curve, as illustrated in Figure 1.

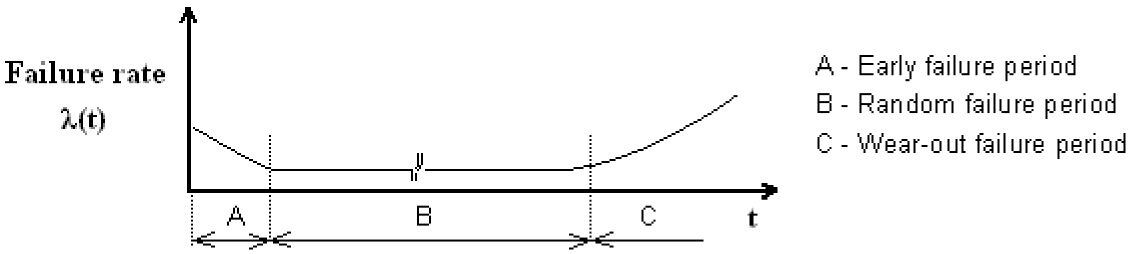


*Fig. 1: Typical "Bathtub" Curve showing the relationship between failure rate and product lifetime*

The Figure 1 shows that the theoretical „life characteristic curve“ has three distinct periods. The initial early failure period is sometimes called the infant-mortality or the burn-in or the debugging period. The initial decreasing failure rate is due to early failure of substandard products. Failure mechanisms during the infant mortality may arise from random defects built into the product during the manufacturing process. Manufacturing defects, latent material defects, poor assembly methods, and poor quality assurance can

[1] *Ing. Radovan Novotný*
*Brno University of Technology*
*Faculty of Electrical Engineering and Communication*
*Department of Microelectronics*
*Údolní 53, 602 00 Brno*
*Email: novotnyr@feec.vutbr.cz*

*Ing. Josef Bradík*
*Brno University of Technology*
*Faculty of Electrical Engineering and Communication*
*Department of Power Electrical and Electronic Engineering*
*Technická 8, 616 00 Brno*
*Email: bradik@feec.vutbr.cz*

contribute to a high initial failure rate. The early failures in this region could be eliminated by a 100% "burn-in" (for components and parts) or by initial "debugging" (of a complex system).

Screening and burn-in of products are often performed to weed out infant mortality before use or delivery. The term "screening" mean the use of some environmental stress as a screen for reducing infant mortality defects. Burn-in is an effective means for screening out defects contributing to infant-mortality. For the producer is the purpose of this testing (1) weed out defective or unsatisfactory product and (2) eliminate “infant mortality” before delivery to the customer. Burn-in process of electronic devices combines electrical stresses with temperature for a given period of time. In practice, the underlying mechanisms of the burn-in process are frequently so complicated that an empirical approach is necessary. The problem studied in this paper is sequential experimental determining the burn-in process conditions giving an optimum results.

### *1.2 Design of experiment*

The design of experiments enables to plan an experiment that simultaneously alters a number of variables in an experimental system to see how they affect and interact to affect responses. An experiment consists of testing combinations of different values (termed levels) of factors thought likely to influence the characteristic (so called response) of interest. If the factors are not independent, their interaction may also be considered. The interaction among factors refers to that the average effect of one factor depends on the level of another factor.

Tab. 1: The L-9 orthogonal array

| | Levels of adjustment for factor | | | |
|---|---|---|---|---|
| Trial | A | B | C | D |
| 1 | A(1) | B(1) | C(1) | D(1) |
| 2 | A(1) | B(2) | C(2) | D(2) |
| 3 | A(1) | B(3) | C(3) | D(3) |
| 4 | A(2) | B(1) | C(2) | D(3) |
| 5 | A(2) | B(2) | C(3) | D(1) |
| 6 | A(2) | B(3) | C(1) | D(2) |
| 7 | A(3) | B(1) | C(3) | D(2) |
| 8 | A(3) | B(2) | C(1) | D(3) |
| 9 | A(3) | B(3) | C(2) | D(1) |

The change in the average response as a factor is varied is called the main effect of that factor. In a factor with two levels, the main effect is the average of all runs at the high level of the factor minus the average of all runs at the low level of the factor. To dampen the effect of systematic changes, the trials should ideally be conducted in a random order, known as randomisation, and replicated.

| Factors | Level 1 | Level 2 | Level 3 |
|---|---|---|---|
| A: Temperature [°C] | 25 | 40 | 55 |
| B: Voltage [V] | 9 | 12 | 15 |
| C: Time [s] | 60 | 240 | 420 |
| COLUMN UNUSED | *UNUSED* | ------------ | ------------ |

*Fig. 2: Experimental factors and their levels for screening burn-in process*

A full factorial experiment combines the levels of each factor with each of the levels of all the remaining factors. The full factorial design has the advantage of being able to estimate interactions between factors. However, full factorial designs become very large as the number of factors and levels increases.

It is possible to investigate the main effects of the factors and their more important interactions in a fraction of the number of runs required for the full factorial experiment. These fractional factorials experiments are useful because they require much fewer runs, although they do not allow the separation of main effects from high-order interactions.

| | A | B | C | - |
|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 0 |
| 2 | 1 | 2 | 2 | 0 |
| 3 | 1 | 3 | 3 | 0 |
| 4 | 2 | 1 | 2 | 0 |
| 5 | 2 | 2 | 3 | 0 |
| 6 | 2 | 3 | 1 | 0 |
| 7 | 3 | 1 | 3 | 0 |
| 8 | 3 | 2 | 1 | 0 |
| 9 | 3 | 3 | 2 | 0 |

| | Levels of adjustment for factor | | | |
|---|---|---|---|---|
| Trial | A | B | C | - |
| 1 | A(1)= 25°C | B(1)= 9V | C(1)= 60s | - |
| 2 | A(1)= 25°C | B(2)= 12V | C(2)= 240s | - |
| 3 | A(1)= 25°C | B(3)= 15V | C(3)= 420s | - |
| 4 | A(2)= 40°C | B(1)= 9V | C(2)= 240s | - |
| 5 | A(2)= 40°C | B(2)= 12V | C(3)= 420s | - |
| 6 | A(2)= 40°C | B(3)= 15V | C(1)= 60s | - |
| 7 | A(3)= 55°C | B(1)= 9V | C(3)= 420s | - |
| 8 | A(3)= 55°C | B(2)= 12V | C(1)= 60s | - |
| 9 | A(3)= 55°C | B(3)= 15V | C(2)= 240s | - |

*Fig. 3: The L-9 orthogonal array and the experimental plan for screening burn-in process*

## *1.3 Experimental design by using orthogonal arrays*

An efficient way to study the effect of several factors simultaneously is to use fractional factorial experiments using standardized orthogonal arrays. These arrays allow for the maximum number of main effects to be estimated in an unbiased (orthogonal) manner, with a minimum number of runs in the experiment.

There are a number of orthogonal arrays to accomplish experiment design. Each array can be used to suit a number of experimental situations. Orthogonal arrays are used to design experiment and describe trial conditions. For example, the L-9 orthogonal array is constructed to accommodate four factors (A, B, C and D), each adjusted at three levels: e.g. A(1), A(2) and A(3), see Tab. 1.

As depicted in the Tab. 1, the L-9 experiment consists of nine rows and four columns where each row corresponds to a particular trial and each column identifies settings of a experimental factors. In the first trial, for example, the four experimental factors are set at their low level (level = 1). In the second trial, the first factor is set at level 1 and the remaining tree factors are set to level 2, and so on.

A common approach is to analyse the result of repetitive runs, or a single trial, through the Analysis of Variance (ANOVA) and the Analysis of Means (ANOM). By studying the main effects of each of the factors, the general trends of the influence factors, towards the product, or process, can be characterised. The contribution of individual quality influencing factors is the deciding key of the process control. Thus, the levels of influencing factor, to produce the best results, can be predicted.

The methodology for design of experiment by using orthogonal arrays is essentially the six steps procedure:

(1) Recognition of and statement of the problem. At the first stage, clear statements of the problem and the objectives or the desired state must be established.

(2) Plan the experiment. It contains selection of the factors, levels, response variable(s) and appropriate orthogonal array. There are a number of software packages, for example the Design Expert or the Qualitec-4, to accomplish experiment design.

(3) Conduct the experiment and collect data. The planned trials are carried out and the raw performance index or response of the process for each experiment is tabulated.

(4) Analyse and interpretation of the experimental results. The experiment stage includes the data analysis and interpretation of results.
(5) Confirm the conclusions by performing confirmation experiment.
(6) Recommendations and conclusions.

| Factor | DOF (f) | Sum of Sqrs. (S) | Variance (V) | F - Ratio (F) | Pure Sum (S') | Percent P(%) |
|---|---|---|---|---|---|---|
| A: Temperature [°C] | 2 | 194.889 | 97.444 | 11.539 | 178 | 50.251 |
| B: Voltage [V] | 2 | 54.221 | 27.11 | 3.21 | 37.332 | 10.539 |
| C: Time [s] | 2 | 88.221 | 44.11 | 5.223 | 71.332 | 20.137 |
| Other/Error | 2 | 16.888 | 8.444 | | | 19.073 |

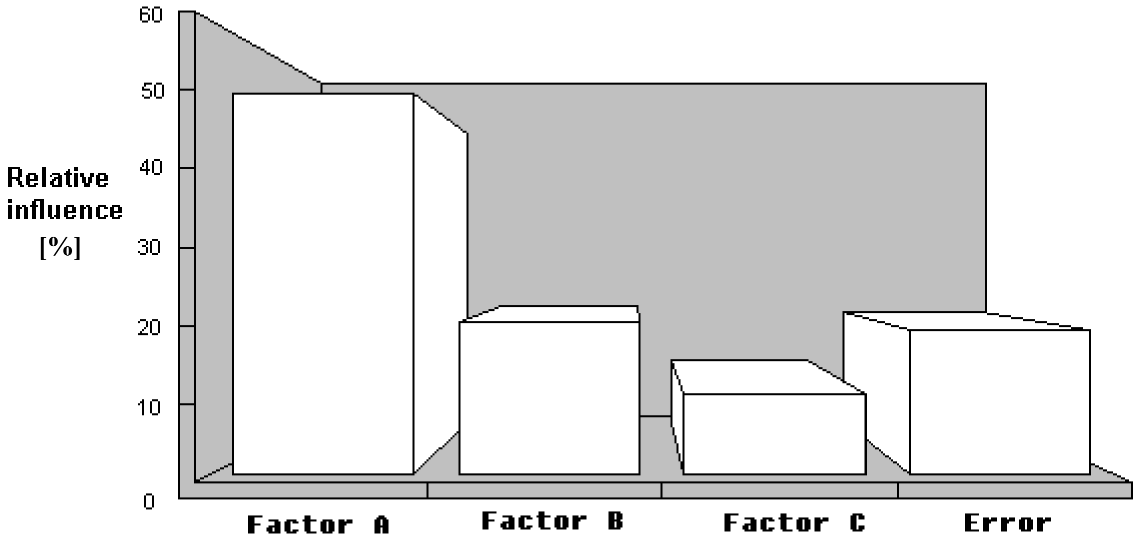


*Fig. 4: The ANOVA table and relative influence of experimental factors*

## 2 Design and analysis of pilot experiment in optimisation of burn in process

### *2.1 Recognition of and statement of the problem and plan the experiment*

Burn-in process of electronic devices generally combines electrical stresses with temperature for a given period of time. Therefore it is assumed that there are three experimental factors, and we select three levels for each of these factors, see Fig. 2. The Fig. 3 shows the L-9 experimental plan for our screening experiment of the burn-in process. This plan we created by using Qualitec-4 software.

### *2.2 Conduct the experiment and collect data.*

Results of the particular trials are summarized in the Tab. 1. As a response we calculated yield, i.e. the percentage of nonconforming devices produced in the burn-in process.

Tab. 2: Experimental results

| Trial | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Yield [%] | 55 | 52 | 55 | 44 | 47 | 43 | 52 | 44 | 35 |

*2.3 Analyze and interpretation of the experimental results*

From our nine trials we can evaluate the relative influence of the experimental factor and determine significant factors by using Analysis of Variance (ANOVA) techniques, see Fig. 4. Furthermore we can evaluate the average effects of particular experimental factors, see Fig. 5.

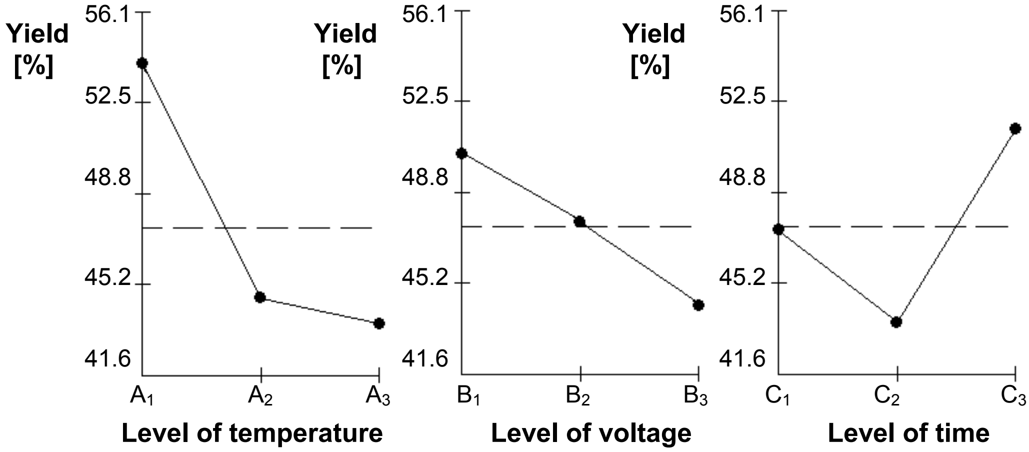


*Fig. 5: Graphical expression of average effects of particular experimental factors*

The Figure 6 shows the two graphs of interactions between two factors. This allows the first view to these aspects of our modification of burn-in process.

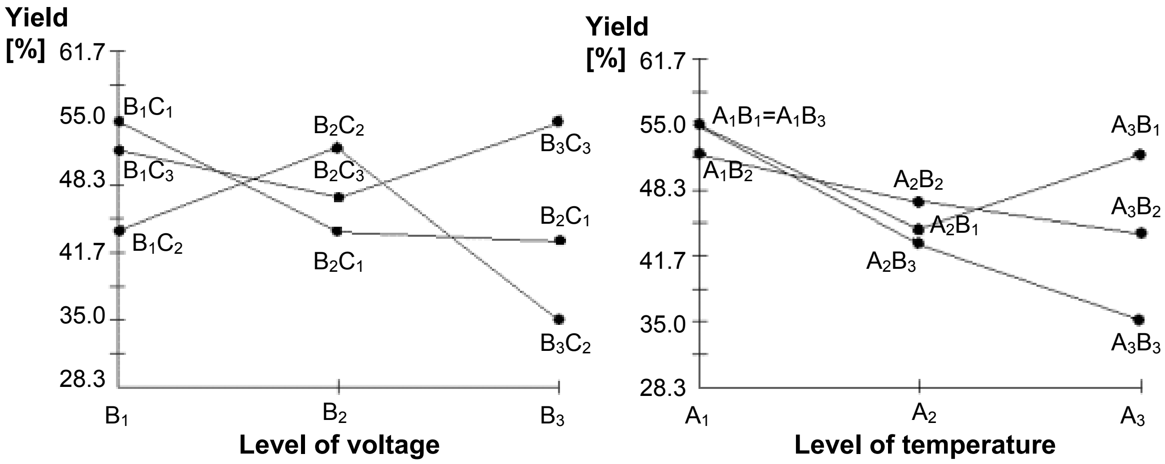


*Fig. 6: Graphical expression of interaction effects: (a) Interaction between voltage and time,*
*(b) Interaction between temperature and voltage*

## 3 Summary

One of the most important problems in industrial research is the discovery of the optimum conditions of technological process. In some cases it is possible to calculate the optimum conditions on theoretical grounds, much more often, however, only an empirical approach is possible.

This search for optimum conditions moreover has in many cases to be carried out on a scale where not only is experimentation costly but the experimenter is under the severe limitation that nothing he does must cause any serious drop in plant efficiency.

Considerable thought has been given to this problem, as a result of which methods have been evolved which enable the search for optimum conditions to be carried out with the minimum of experimental effort while at the same time allowing the efficiency of the plant to be progressively improved as the work proceeds. Factorial experiments, fractional factorial experiments and response surface techniques are used to study relationships between factors and identify optimum combinations.

It is unwise to design too comprehensive an experiment at the start of a study. The idea of using information from the early parts of a series of observations to design the later work is termed the sequential approach to the discovery of the optimum conditions of technological process. Sequential experimental approach using information from the series of small pilot experiments, which provides approximate information.

The understanding of the burn-in procedure is very important question in the electronic industry related to planning and controlling production burn-in of devices. This paper deals with the problem how to follow the factors influencing the burn-in procedure using design of experiments. It also presents the results of one pilot experiment of screening our modification of burn-in process of electronic device. In our investigation to plan and analysis of experiment we use the Qualitec 4 software.

## 4 References

[1] Kececioglu,D.: Reliability and Life Testing Handbook. Prentice Hall New Jersey 1993, ISBN 0 13 772377 6

[2] Nash, F.: Estimating Device Reliability: Assessment of Credibility. Boston Academic Publishers 1993, ISBN 0 7923 9304 X.

[3] Christou, A.: Integrating Reliability into Microelectronics Manufacturing. Wiley, 1996, ISBN 0-471-94407-6

[4] Montgomery, D.: Design and analysis of experiments. Wiley, 1996. ISBN 0-471-52000-4

[5] Kuo, W.-Chien-W. – Kim, T.: Reliability, Yield, and Stress Burn-in. An Unified Approach for Microelectronics Systems Manufacturing and Software Development. Kluwer Academic Publishers, USA 1998, ISBN 0-7923-8107-6

Acknowledgement

This research has been supported by the Czech Ministry of Education under the contract FRVS 1958/2002 G1, and by the Czech Ministry of Education in the frame of Research Plan MSM 262200022 *MIKROSYT Microelectronic Systems and Technologies*.