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METHODS FOR ACCELERATED LIFE TESTING OF MICRO SWITCHES IN VEHICLES

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ABSTRACT
Our aim is to obtain reliable test results for determining the product's life cycle of micro switches. The requirement producing products with high reliability have increased the need for testing of components. Systems generally require system components having predetermined reliability during a determined time. It is difficult to assess reliability with traditional life tests recording only failure times. A relationship between component failure and operational conditions makes it possible to use accelerated models and to predict failure-time distribution. In addition, we use the factorial experiment design method to design the tests. Our goal is to use this to draw conclusions about product life.

1. INTRODUCTION

In everyday life, we often come across micro switches, and this is no different for vehicles. In passenger cars, several functions can be operated with the help of micro switches, such as the index, the hazard warning button and various functions on the dashboard.

The topic of the research is the investigation of accelerated lifetime data of micro switches. The micro switch test bench designed for this purpose can test four products at the same time [4, 5]. The tests reveal the operating conditions under which a higher load than normal load can be applied. The design, operation and testing process of the apparatus have been previously described. In this article we introduce the basics of experimental design methodology and how we can analyse the investigated structural elements using the experimental design methodology.

The constant evolution of the market requires the development of more innovative products than ever, all of which must be performed with ever-increasing technological content and in record time, while improving productivity, product reliability and quality. Nowadays in the industrial practice, traceability is becoming more and more important, as customers demand not only high quality but also its professional proof. There are several experimental design methods for controlling these processes, so many industries are using experimental design methods to test the quality of processes and products. The basics of experimental design were made possible by Ronald Fischer's statistical analyzes. The common methods can be divided into three groups *(Table 1.)* [1-3].

Table 1. Classification of statistical experiment design types

Factorial plans	
•	Chane factor level one by one
•	One factors
•	Group factors
•	Full factorial
•	Partial factorial
•	Shainin
•	Taguchi
Interface design	
•	Gauss-Seidel
•	**Gradient (Box-Wilson)**
•	Simplex
•	Method of Stochastic Approaches
Square plans	
•	Latin square
•	Greek - Latin square
•	Hiper Greek- Latin square
•	Youden square
•	Lattice square

Factorial designs allow multiple factors to be examined simultaneously. To reduce the number of attempts, the number of settings tested is usually maximized to two per factor. This value is sufficient to indicate the importance of the factors and, in some cases, to determine the optimum setting range. They are simple and logical to handle and therefore excellent and easy to use in industrial practice. In recent years, the industry has favoured simplified methods such as Shainin and Taguchi factorial methods. The response interface methods are used to model the curve fields and to examine the relationships in detail. The advantage of the methods is that the predefined experimental instructions make it possible to construct a mathematical model of the curve fields. Square designs can be used to simultaneously analyse a factor with more than two options. However, the number of factors should be limited for ease of use. An analysis of the experiments performed gives information on the importance of the factors [2].

1.1. The steps of the experimental design

The more precisely an experiment is designed, the less effort it takes to execute it and the more reliable the conclusion from the evaluation of the experiment is. It follows that the design phase is most accurate, but great care must also be taken in estimating interactions and in designing the factors to be considered.

Preparation	Determination of factors • Selection • Units • Measurement accuracy • Measurement mode Factor levels Optimal parameters
Designing	Estimation of interactions Selecting an experimental design method Preparation of the experimental design
Implementation	Setting of parameter Definition of the quality features
Analysis	Graphical method Statistical method Determination of optimal factor levels or Return to preparation or designing
Validation experiments	Designing Implementation Evaluation

Figure 1. Steps of the experimental design [2]

2. THE TWO LEVELS OF EXPERIMENTAL DESIGN

Based on the type of statistical experiment design, we will choose the Box-Wilson method to apply *(Table 1)*. When using this method, each factor in a series of experiments will be set to one level once and once to another level. Therefore, ch factor will have only two levels. Number of experimental settings that realize all possible level combinations of factor k (k is the number of factors):

$$N = 2 \cdot k\,, \tag{1}$$

when designing our experiments, one level of the factors is *+1* and the other level is *-1*. It does not matter whether the lower or upper level is denoted by *+1* or *-1*, respectively. These specified levels will represent specific physical quantities during the tests, such as the amount of a given factor. The experiment should be designed so that each factor appears at the same level as the *+1* level, and the factor combinations appear in the same amount at the *+1* level as the *-1* level. This is shown in the experimental matrix (see *Table 2.)* [1].

2.1. Experimental matrix

The experimental matrix summarizes all possible experimental settings and systematically shows the results of the experiments *(Table 2.)*. The rows in the matrix represent one experiment, that is, it shows the adjustment levels of the factors in one experiment. Each column of the experimental matrix helps calculate the effect of each factor. To fill in the columns of the table, we use the sign rotation method. For the first factor, the signs are rotated individually, for the second factor two, for the third factor four. In the cross-effect columns, we multiply the columns of the factors involved in the cross-effect by determining the signs. The product of two identical signs is always '+' and the product of two different signs is always '-' [1].

Table 2. Experimental matrix

Number of the experimental setup serial (*N*)	x_1	x_2	x_1x_2	Experimental result *(y)*
1	-1	-1	+1	y_1
2	+1	-1	-1	y_2
3	-1	+1	-1	y_3
4	+1	+1	+1	y_4

3. COMPLETE FACTORY EXPERIMENTAL PLAN

Experiments in which all possible combinations of levels of factors are determined is a complete factorial experiment. In this case, such an experiment is called a *2k* experiment for a two level experimental design.

Requirements for the factors:

- be controllable,
- be clear,
- be effective, therefore have a significant effect on the result of the experiment,
- have a known and limited set of values,
- factor levels can be set [1,2].

The x_0 column always contains *+1* value. This column will be needed to evaluate the experiments. The column x_1, x_2, x_1x_2 contains the adjustment values for the single factor, and the column contains the experimental results.

The combined effect of all factors can be described by a linear model as follows based on *Table 4.*

We have only two data in one step in the direction of one factor in the *n*-dimensional experimental space, we can lay a straight line at this *2* points. Therefore, the experimental surface to be determined on the basis of the measurement data.

The combined effect of all factors can be described by a linear model as described above [1].

$$y = b_0 \cdot x_0 + b_1 \cdot x_1 + b_2 \cdot x_2 + \ ... + b_N \cdot x_N \quad (2)$$

In (2), we calculate the coefficients b_i ($i=0 \dots N$), which are determined by the experiments, that is, the slope of the response function caused by each factor; while b_0 represents the initial value of the experiments. The number of possible effects, including b_0 the linear effects, and all possible interactions, is equal to the number of settings for the full factorial experiment using the next formula:

$$2^N = \sum_{l=1}^{N} \binom{N}{l}, \qquad (3)$$

where N denotes the number of experimental settings that realize all possible level combinations of factors and l is the serial number of effects examined.

Generally, in a full factorial experiment, the order of the highest order interaction is one less than the number of factors. In our case, the number of attempts in the interaction is *4*, the relation (3) is as follows [2]:

$$2^N = \sum_{l=1}^{N} \binom{4}{2} = 2^4 = 16. \qquad (4)$$

3.1. Determination of the factors and factor levels

We determine the factors and the factor levels. The factors significantly influence the processes. Factor levels are values that can be taken up by factors. These factors and factor levels are summarized in *Table 3.*

Table 3. Determining factors and levels

Number of factors (k)	Number of levels (p)
Factor 1: Micro switch's type	Level 4: *D1, D2, K1, K2*
Factor 2: Switch time (ST)	Level 2: *0.25s; 0.30s*
Factor 3: Relative humidity (RH)	Level 2: *60 %; 80 %*

If all factors can take the same level in an experiment, then the number of all possible factor levels in the experiment is

$$n = p \cdot k, \qquad (5)$$

where n is the number of experiments, p is the number of levels of each factor and k is the number of factors.

In our case the number of levels is *2* and the number of factors is *2*.

According to the formula (4) we should take 16 measurements, because we are testing *4* types of products, but we repeat all *16* type of measurements *10* times, so we will have a total of *160* measurement results.

Generally, a maximum of *15* factors and up to *30* levels are expedient per experiment. There are five basic requirements when designing your experiments.

In our case, the experimental matrix is shown in *Table 2.*, as follows:

Table 4. A 22 type two-factor full experimental matrix

N	Factor (ST) [s]	Factor (RH) [%]	Transformed factors x_0	x_1	x_2	x_1x_2	Exp. result (*y*)
1	0.25	60	+1	-1	-1	+1	y_1
2	0.30	60	+1	+1	-1	-1	y_2
3	0.25	80	+1	-1	+1	-1	y_3
4	0.30	80	+1	+1	+1	+1	y_4
			b_0	b_1	b_2	b_{12}	

4. DETERMINATION OF THE COEFCIENTS b_i

Using the Box-Wilson method, we change the level of each factor at one step in the first set of experiments. Then, we examine which factor has impact on the value of the optimization parameter and we design the next set of experiments based on it. To determine the effect of each factor, it is sufficient to know the slope of the response function for that factor to plan the next step.

Determining the coefficients b_i *in* formula (2) using the experimental matrix is very simple. The signs of each factor are in its own column vector. The column vector of the experimental results y must be scalarly multiplied by the column vector of the given factor and then summed up by the sum of the elements of the column vector. The amount should be divided by the number of items in the column. Mathematically, it can be expressed as follows [1]:

$$b_j = \frac{\sum_{i=1}^{N} x_{ji} \cdot y_i}{N}. \qquad (6)$$

In our case x_{ji} also appears in columns x_0, x_1, x_2 and x_1x_2 as transformed factors as shown in *Tables 2*, *4* and *5*. In our case the type *22* experimental matrix is formed as follows *(Table 5).* Based on equation (6) the coefficients b_0, b_1, b_2 and b_{12} has been determined.

Table 5. Determining factors and levels

i	Factor (ST) [s]	Factor (RH) [%]	Transformed factors x_0	x_1	x_2	x_1x_2	Exp. result (*y*)
1	0.25	60	+1	-1	-1	+1	y_1= 148664
2	0.30	60	+1	+1	-1	-1	y_2= 171711
3	0.25	80	+1	-1	+1	-1	y_3= 100200
4	0.30	80	+1	+1	+1	+1	y_4= 126511
b_0=136711		b_1=12339,5		b_2= -93664		b_{12}=816	

To formulate the relationship between the two interacting factors, we may use the product of the two factors. In the case of two factors.

After determining the values of b_i, we can substitute them into relation (2):

$$y = 136711 + 12339{,}5 \cdot x_1 - 93664 \cdot x_2 \ . \quad (7)$$

However, it is not the best solution to approximate the experimental surface with the linear model. This is due to the fact that there is an interaction between the two factors.

$$\hat{y} = b_0 + b_1 \cdot x_1 + b_2 \cdot x_2 + b_{12} \cdot x_1 \cdot x_2 + \cdots . \quad (8)$$

Substituted in the formula (8) the relationship is as follows:

$$\hat{y} = 136711 + 12339{,}5 \cdot x_1 - 93664 \cdot x_2 + 816 \cdot x_1 \cdot x_2 . \quad (9)$$

5. MEASUREMENTS AND DATA

In our measurements a total of four types of micro switches denoted by *D1, D2, K1* and *K2* are tested, with two different switching times of *0.30 s* and *0.25 s*, with two relative humidity setting *60 %* and *80 %*.

During the tests, *20* of the *4* types of switches at *0.25 s* and *0.30 s* switching speeds have failed. *Table 6.* illustrates the measurement results.

Table 6. Database with failure cycles

	Type	Switch time	Relative humidity	1	2	3	4
1	D1	0.30	60%	131186	171712	168082	100826
2	D1	0.25	60%	165500	148664	139034	139034
3	D2	0.30	60%	180230	191019	196031	189966
4	D2	0.25	60%	182918	170965	205622	225077
5	K1	0.30	60%	134494	197341	182428	197917
6	K1	0.25	60%	138167	212413	99140	185672
7	K2	0.30	60%	134494	180235	212592	209829
8	K2	0.25	60%	196937	134958	154036	91140

The horizontal axis in *Figure 2* represents the time of the test and the vertical axis show the temperature for a switch, as an example. The blue curve indicates one of the micro switch sample D1 temperature suddenly rises to *206.40 °C*, at this point it goes to failure. The green curve is for *K1*, the red curve is for *D2* and the yellow curve is for *K2*. The *Table 7* summarize the data related to the time-temperature diagram.

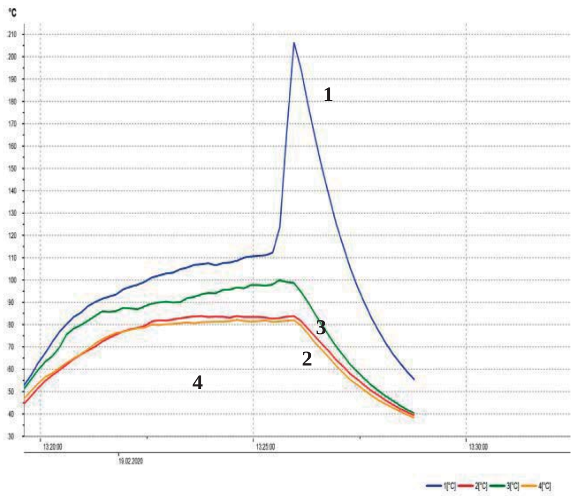

Figure 2. Time-temperature diagram

Figure 3 and *Figure 4* exhibit microscopic images of broken micro switches. The 3D images show the small or large burns on the contacting surfaces of the switches.

Table 7. Details of the time-temperature diagram

Broken switch type:	*D1(blue)*
Failure temperature:	*206.40 °C*
Failure switching cycle:	*100.826 cycle*
Switch time:	*0.25 s*
Relative humidity:	*60 %*

Figure 3. Contacting surface of a micro switch *(Type D1)*

Figure 4. Contacting surface of a micro switch *(Type K2)*

6. EXPERIMENTAL MODEL OF THE RESPONSE FUNCTION

We use a mathematical model of the process to describe the process. The model is the function relation between the optimization parameter y and the factors *ST* and *RH*, the general form of which is the response function φ:

$$y = \varphi(x_1, x_2). \quad (10)$$

To illustrate the relationship between the optimization parameter and the factors, the "black box" likeness is used.

The black box is the process or object under investigation that we want to describe and replace with the mathematical model presented during experiment and implementation. The black box symbolizes the unknown relationship between the *ST* and *RH* factors acting on it as input and the optimization parameter *y* as output [2].

Figure 5. The "black box"

In the case of two factors, the response function can be represented in space, as illustrated in *Figure 6*. Here, the *ST* and *RH* factors are on the horizontal plane, while the values of the optimization parameter *y* plots the surface of the response function, the highest point of which indicates the desired optimal setting. Now, we see only a small rectangular part of the response function with the number of failure cycles of *171 711* created by setting a switching speed of *ST = 0.30 s* and a relative humidity of *60%.*

The failure rate for the *148 664* cycle was obtained by setting a switching speed of *ST = 0.25 s* and a relative humidity of *60%*. Cycle *126 511* was generated with a switching speed of *0.30 s* and 80% humidity setting, while *100 200* was generated with a switching speed of *0.25 s* and *80%* humidity setting.

Table 8. Determining factors and levels

ST	*RH*	*y*
0.30 s	60 %	171711
0.30 s	80 %	126611
0.25 s	60 %	148664
0.25 s	80 %	100200

Based on the above calculations, we can conclude that the best results are obtained when tested with a switch time of *0.30 s* and humidity setting of *60%* and the worst results is obtained by settings a switch time of *0.25 s* and *80%* humidity.

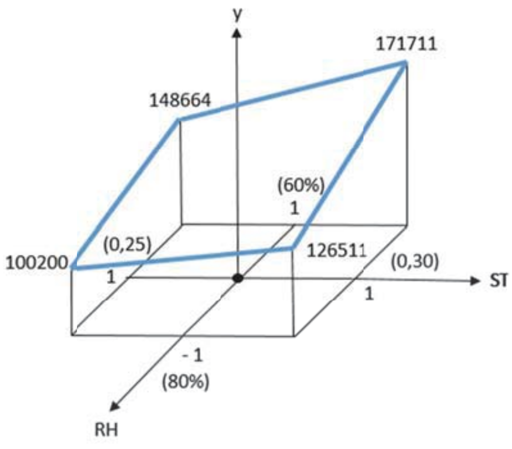

Figure 6. The response function φ for two factors, with the linear model [2]

7.SUMMARY

In this paper the experimental design methods used for testing micro switches are presented. By selecting the Box-Wilson method, we determined all possible level combinations of factors and the number of experimental settings.

The experimental matrix summarizes all possible experimental options and the results of the experiments are plotted. Each column of the experimental matrix provided help in calculating the effect of each factor.

On the base of our experiments we defined the relationship suitable for the calculation of the b_i coefficients using the experimental matrix. It gives us more information on how to estimate the lifetime for these devices. The temperature-time diagram of a test and some 3D microscope images of broken contacting surfaces are illustrated to show the failures of the contact surfaces.

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NEMZETI KUTATÁSI, FEJLESZTÉSI ÉS INNOVÁCIÓS HIVATAL

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