

SOFTWARE FOR THE ANALYSIS OF THE COMPLETE FACTORIAL EXPERIMENT IN MECHANICAL ENGINEERING

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ABSTRACT: The objective of the factorial experiment is establishing the model, in the first phase linearly polynomial of the investigated system. The random balance method is an experimental statistic pre-modelling method which was used for determining the order of influence of the process parameters. For this, the chosen performance criteria were taken into consideration. The influence order according to the performance criteria has been exemplified in this paper using virtual devices. Thus, with the help of the *Factorial Experiment* this order of influence on the process of the previously enumerated parameters was determined. The experimental method presented is a point of view checked from several parts and well founded both theoretical and experimental. The software done and presented in this paper allows the memorizing of all experimental data, manipulating information in the desired way, as well as marking some graphs for the determined sizes using over three hundred thousand points of influence.
KEY WORDS: experiment, factorial, software, database, method

1 INTRODUCTION

By applying science as a productive force, people’s work moves more and more toward the reasoning and decision taking activity, the operation work being gradually taken by machines and automatic equipments.

The experiment has always served as a mean of knowing the surrounding reality, being a control criterion of hypothesis and theories.

For a long time it was believed that choosing the strategy of the experiment and making it is determined by the experience and intuition of the person making the experiment, mathematics being used only for processing data.

The vertiginous increase of the experimental researches’ volume has brought to the centre of attention the problem of increasing the efficiency of the experiment; the appearance of electronic computers has allowed such experimentation schemes to take place that will contribute to the sensible increase of efficiency in research.

In this context the mathematical theory of experiment appeared and within it experiment programming (organization).

The experiment is programmed according to a determined plan, previously established, optimal from the point of view of the factors’ modification algorithm, its realization ensuring a complex influence on the variable states of the researched object.

The diversity of the purposes aimed at in research generate a multitude of experimental programmes, the theory of the mathematical experiment putting at one’s disposal a series of concepts necessary for reaching the purposes of the research. [174], [238].

2 THE EXPERIMENT AN ESSENTIAL PROBLEM IN THE FIELD OF ENGINEERING

The experiment (experimental research) represents a controlled intervention in the evolution (functioning) of a system, having as an end result:

- controlling and improving knowledge regarding the action of the influence factors on the response functions of the system (passive experiment, for evaluation and certification of a state of fact);
- determining the optimal functioning conditions of a system in relation to imposed criteria and restrictions (active, optimization experiment);

Under current conditions the representation of the experiment is very useful (especially of the one with technological finality) as a cybernetic system (figure 1) [174].

The research object integrates the system subject to experimental research (a real physical system or a physical model of it) with the multitude of research (testing) and measuring means necessary for the evaluation of the state, behaviour and evolution of that particular system.

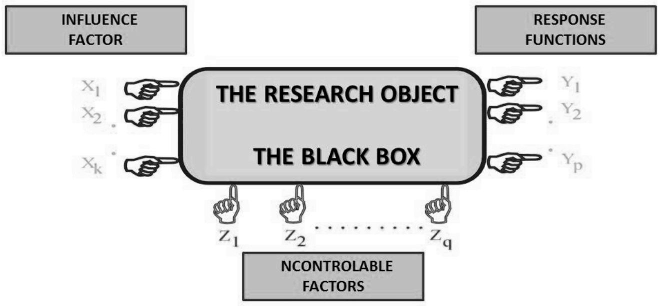

Figure 1. Cybernetic system of the experiment

The response functions (objective functions, performance indicators, optimization criteria) define and qualitatively evaluate the behaviour and evolution tendencies of the system which constitutes the object of research under the given conditions. Based on their nature, the response functions can be economical (costs, profit, productivity), technical-economical (physical production, quality and reliability of the products), technological (productivity, physical-chemical and mechanical properties of the material, precision of execution of the products), ergonomic, esthetical or complex.

The influence factors (independent variables) represent modalities and means of influencing the behaviour of the research object corresponding to the objectives of the experiment.

The experiment structure is the definition by the number and unfolding conditions of the attempts necessary and sufficient for accomplishing the objectives of the research.

For the elaboration of the structure of the experiment taken into consideration, the type of factorial experiment of the ***k***-order, the following were taken into consideration:

- within an attempt, each factor was able to take only one of the multitude of values available in its field of existence;
- determined amount of factors levels has defined/defines one of the possible states of the object of research and has materialised the possibility of making an attempt;
- the amount of possible combinations of the levels of influence factors has determined the amount of research object states and thus, the volume of the experimentation was:

$$N = p^k \quad \text{attempts} \qquad (1)$$

where: k – is the number of factors, and p – the number of variation levels of the factors

- accomplishing the objectives of the research in the situation in which the experiment was not absolutely controllable (there are always uncontrollable factors that operate on the research object, such as temperature, pressure and humidity of the ambient environment) and its results are not perfectly reproducible (there are always errors and measuring uncertainties), often comply us to replicate the attempts, meaning to repeat them by reducing the research object under the initial conditions (the repeated measuring of the object function or of its elements within the same attempt is not replication) thus, 3(three) replicas were done for each case under the same initial conditions;

The complete definition of an experiment structure requires the mentioning of the effectuation succession of the scheduled attempts.

The general ***algorithm*** of a modern experimental research, algorithm that was otherwise used, was intuitively represented in figure 2. [174], [238].

The existence of complete investigation cycles is noted, iteratively organized and symbolically placed on a convergent spiral toward the objectives of the experimental research.

Each cycle has included 4(four) consecutive stages, namely:

- the thorough knowledge of the research object and, based on this, adopting the initial structure of the mathematical model that connects the answer functions to the existing influence factors;
- designing the experimentation programme corresponding to the number and levels of variation of the influence factors, as well as the number of replicas and necessary randomization.
- the actual making of the experimentation programme associated to a given experimentation cycle;
- the statistic analysis of the experimental results obtained, finalized by estimating the regression coefficients, testing the adequacy and establishing the reliance (precision) interval of the mathematical model initially adopted;

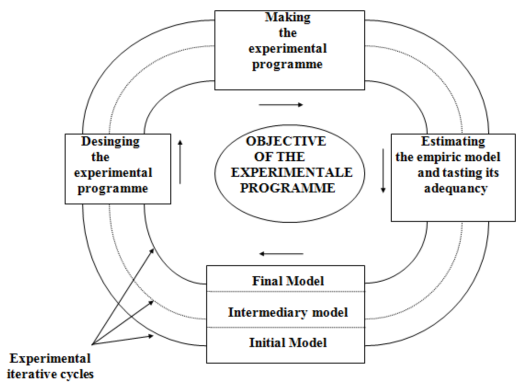

Figure 2. General algorithm of an experimental research

The inadequacy of the current mathematical model requires initiating the next investigation cycle, for the designing of which all information obtained in the previous cycle will be taken into consideration

While the experimental research takes place, considered as a whole, the structure of the initial mathematical model and the experimentation programme can be subject to correction of eliminating or adding influence factors, of modifying the variation fields of the factors, of introducing a response function, and so on.

3 FACTORIAL EXPERIMENT

Establishing the initial experimentation field requires:

- establishing the definition field of the factors;
- analyzing the prior information regarding the modification of the objective function at small variations of the influence factors;

Practically, establishing the field of experimentation is done in two stages:

- establishing the basic level (the central point of the experimentation);
- Establishing the variation interval;

As it was mentioned before, [174], for the first stage of research, the variation of factors on two levels is sufficient, immediately resulting the maximum volume of the experimentation $N = 2^k$.

The experiment is called complete factorial, in the case in which all possible combinations of the levels of factors are included.

The programme matrix of the experimentation is done tabular, on the columns figuring the factors, and on the lines the component attempts of the programmes. The level of factors are marked in codified values (+1) and (-1). The values of the objective function y, have been experimentally determined.

The objective of the factorial experiment is establishing the model, in the first phase linearly polynomial of the investigated system, meaning determining the concrete value of the $\mathbf{b_j}$ coefficients in the following relation [174], [238], [47].

$$\widetilde{y} = \sum_{j=0}^{k} b_j x_j \qquad (2)$$

If it is admitted that each factor has *p = 2 levels of variation* then, the volume of the complete factorial experiment is $N = 2^k$ attempts that need to be done under the conditions:

- randomizing the succession of attempts;
- replicating the attempts (if the case); in this situation one is going to work with the arithmetic average of the replicas' results for each attempt, $\widetilde{y}_i$;
- keeping the homogeneity of the empirical dispersions for each $\mathbf{s^2_i}$ attempt;

The main information carriers are the regression coefficients through their numerical value and sign. The analysis of the regression coefficients allows us to estimate the amplitude and the influence direction of the factors.

From this point of view there are two characteristic situations:

- the coefficients are significant;
- the coefficients are insignificant.

If all coefficients are significant, it is very important that their values are relatively close (the same order of size), which indicates the fact that the model is close to the optimal field in relation to all factors analyzed.

If part or all coefficients are insignificant, this can be owed, on the one hand, to the experimentation conditions, in the sense that the variation intervals of the factors were too narrow or the experimentation error was too big. In this situation, it is recommended that the research be redone with the adequate correlations.

4 THE PROCESS OF DIMENSIONAL PROCESSING BY ELECTRICAL EROSION WITH MAGNETIC ACTIVATION SUGGESTED AS CYBERNETIC SYSTEM.

Assisted programming of experiments at the dimensional processing by electrical erosion with magnetic activation for validating in general some theories, casts aside mistakes, compromises and puts order into thoughts, design, planning and leading.

Processing experimental data by statistic methods requires knowing very well some necessary knowledge.

The analysis of complex technological processes, amongst which the procedure of dimensional processing by classical electrical erosion, but with magnetic activation too, [174] can be done through various methods.

One of these methods is the systematic approach where the central element of this manner of looking at reality is the system. [239]

The system, [238], [239], [240], defined by the dimensional processing by electrical erosion with magnetic activation, represents a complex of independent objects that function together for a common objective with inputs and outputs in an organized transformation process.

In the study, analysis and leading process of the processing by electrical erosion with magnetic activation process one seeks certain optimal conditions of the researched object using mathematical shaping.

This mathematical shaping will have 2 (two) components:

- a theoretical component, which in fact represents a physical-mathematical modelling of material sampling at the processing by electrical erosion with magnetic activation. The physical-mathematical modelling refers to the design, foundation, control and suggestion of the author of a physical-mathematical model of the material sampling process at the electrical erosion processing with exterior magnetic activation;
- an experimental component which has the purpose of also indirectly controlling the suggested and theoretically proven theory by the suggested theoretical physical-mathematical modelling.

In another order, referring to the experimental modelling suggested and presented in the present chapter of this doctoral dissertation the modelling is based on a mathematical algorithm made out of equations which correctly describe the inter-dependencies between the variables of the analyzed process.

The algorithm used has the following stages:

- formulating the model:
- establishing the scope;
- delimiting the process;
- establishing variables;
- establishing the type of model.
- establishing the objective function.
- establishing the equations of the mathematical model.
- controlling the suggested model with errors analysis and computer simulation.

The literature dedicated for studying technological objects, [174], [238], underlines the fact that for studying kinematics and the mechanisms of the electrical erosion processing a programming of the experiments is required in order to establish a mathematical model well founded.

Thus, **the stages** that were tackled in order to prepare the experiments were:

- The processing of the antecedent information and the elimination of the insignificant parameters factors;
- Obtaining the mathematical model of the object subject to research under the form of a mathematical function;
- Finding an optimal field.

The models of the preliminary research taken into consideration are: the rank correlation method, the dispersion analysis, the random balance analysis, methods that basically require the creation of some experiments for selecting parameters and significant factors of the process.

The basic research methods are based on classical experimental programmes and the active experiment programmes.

Statistic modelling was mainly done in 2(two) stages, namely:

- pre-modelling;
- the actual modelling;

Pre-modelling had a well established purpose which in the end was reached in 4(four) stages:

- establishing the state variables and the process parameters;
- determining some limits and variation intervals of the process parameters;
- establishing an experimental error, as well as the means of reducing it;
- naming the interactions and the degree of connection between the state variables and the process parameters.

The actual statistic modelling was done by active experiment.

In order to obtain a programming of the lab experiments at the dimensional processing by electrical erosion with magnetic activation the active experiment method was used, namely a complete central factorial experimentations programme composed $\mathbf{2^n}$ where **n=4** was done.

5 SOFTWARE FOR THE ANALYSIS OF THE COMPLETE FACTORIAL EXPERIMENT AT THE DIMENSIONAL PROCESSING BY ELECTRICAL EROSION WITH AN ENSEMBLE OF EXTERIOR MAGNETIC FIELDS

The following parameters were taken into consideration:

- The intensity of the electrical current: I [A];

- The impulse time t_i [μs];
- The pause time: t_p [μs];
- The material of the object to be processed;
- The material of the transfer object;
- The intensity of the magnetic field: H [A/m], (or the induction of the magnetic field: B [T]);
- The polarity of the processing
- The direction (sense) of the magnetic field lines

The variation fields of the main parameters are presented in Table 1:

Table 1. Variation of the main parameters

I [A]	12.5 / 37.5
t_i [μs]	24 / 95
T_p [μs]	12 / 48
Intensity of the magnetic field [A/m]	H1 = 54219 / H2 = 71022 H3 = 108809 / H4 = 233600 H5 = 350000

The objective functions that the software components calculate are:

- Productivity of the processing: Q_P [mm^3/min];
- Volume wear: Q_E [mm^3/min];
- Relative wear : γ [%];
- Specific energy consumption: W_e [J/mm^3];
- Quality of the processed surface: R_a [μm].

The objective functions are presented in Table 2.

For making the programme packages [1] a complete central compound factorial experiment was used being based on a complete factorial experiment $\mathbf{2^4}$, namely two measure on each axis corresponding to every influence factor.

This type of experiment represents a standard central compound experiment in the sense of the experimental statistic modelling programme.

A complete central compound factorial experiment was used because a factorial experiment of the order **I** did not provided estimations of the results with a satisfying precision. [174].

The objective function "Quality of the processed surface R_a" and the programme code which calculates R_a for approximately 350000 points are presented in figure 3.

Parts of the data obtained are presented in figure 4.

```
'Ra = 6,72173 + (-0,0443228)·tp + (-7,30174·10-4)·ti + (-0,809742)·I + (2,38057·10-5)·H + (1,27152·10-4)·tp·ti
'+ (-1,90972·10-3)  ·tp·I + (-3,20095·10-6)·tp  ·H +(-6,07394·10-3)·ti·I + (7,42738·10-7)·ti·H + (-2,44141·10-6)·I·H+(1,32791·10-3)  ·tp2
'+ (2,42992·10-4)·ti2 + (0,104496)  ·I2 + (2,7042·10-9)  ·H2
Public Sub calt_supraf()
'program care calculeaza calitatea suprafetei pentru toate cazurile
Dim db As Database
Dim intmag(5) As Double
Dim tabcalsupraf As Recordset
Set db = CurrentDb()
Set tabcalsupraf = db.OpenRecordset("calitsupraf", dbOpenDynaset)
intmag(1) = 54219
intmag(2) = 71022
intmag(3) = 108809
intmag(4) = 233600
intmag(5) = 350000
Dim H, tp, ti, i As Integer

With tabcalsupraf
For H = 1 To 5
    For tp = 12 To 48
        For ti = 24 To 95
            For i = 12.5 To 37.5
                .AddNew
                ![ticamp] = ti
                ![tpcamp] = tp
                ![icamp] = i
                ![Hcamp] = intmag(H)
                ![Ra] = 6.72173 + (-0.0443228) * tp + (-7.30174 * 0.0001) * ti + (-0.809742) * i + (2.38057 * 0.00001) * intmag(H) + (1.2715
                        + (-1.90972 * 0.001) * tp * i + (-3.20095 * 0.000001) * tp * intmag(H) + (-6.07394 * 0.001) * ti * i + (7.42738 * 0.
                .Update
            Next
        Next
    Next
Next
End With
```

Figure 3. Factor R_a analysis

nrcrt	Ra	Tpcamp	Ticamp	Icamp	Hcamp	Click to Add
359641	16.3820329356842	12	24	12	54219	
359642	17.8836289268942	12	24	13	54219	
359643	19.5942169181042	12	24	14	54219	
359644	21.5137969093142	12	24	15	54219	
359645	23.6423689005242	12	24	16	54219	
359646	25.9799328917342	12	24	17	54219	
359647	28.5264888829442	12	24	18	54219	
359648	31.2820368741542	12	24	19	54219	
359649	34.2465768653642	12	24	20	54219	
359650	37.4201088565742	12	24	21	54219	
359651	40.8026328477842	12	24	22	54219	
359652	44.3941488389942	12	24	23	54219	

Figure 4. Values calculated for R_a

The graph of the results for R_a is presented in figure 5.

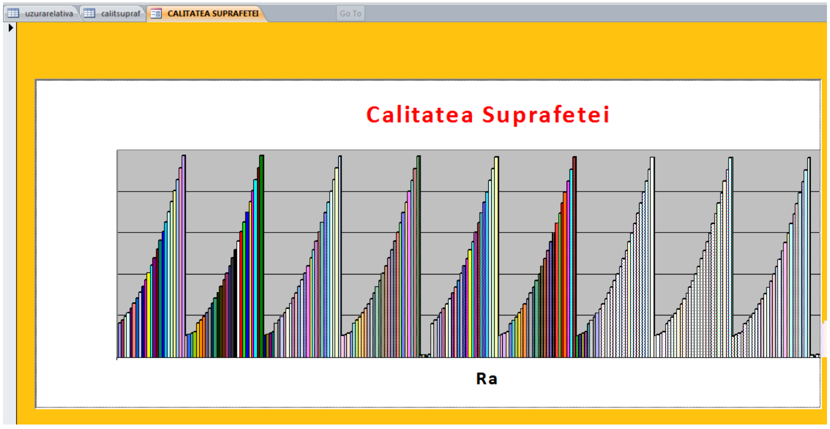

Figure 5. The graph for R_a values

The software allows calculations and marking the diagrams for the objective function "Relative wear", figure 6.

```
 'gama = 17,1382 + (-0,48513)·tp + (-0,493938)·ti + 2,31266·I + (8,95959·10-5)·H + (4,12754·10-3)·tp·ti +
'+ (-0,0754861)  ·tp·I + (6,575552·10-6)·tp  ·H + (-0,0649648)·ti·I + (2,31074·10-6)·ti·H +
'(-3,04687·10-5)·I·H+0,011734·tp2 + (4,93132·10-3)·ti2 + 0,389499·I2 + (-3,01084·10-9)  ·H2
Public Sub uzurarelativa()
'program care calculeaza uzura_suprafetei pentru toate cazurile
Dim db As Database
Dim intmag(5) As Double
Dim tabuzurarelativa As Recordset
Set db = CurrentDb()
Set tabuzurarelativa = db.OpenRecordset("uzurarelativa", dbOpenDynaset)
intmag(1) = 54219
intmag(2) = 71022
intmag(3) = 108809
intmag(4) = 233600
intmag(5) = 350000
Dim H, tp, ti, i As Integer

With tabuzurarelativa
For H = 1 To 5
    For tp = 12 To 48
        For ti = 24 To 95
            For i = 12.5 To 37.5
                .AddNew
                ![ticamp] = ti
                ![tpcamp] = tp
                ![icamp] = i
                ![Hcamp] = intmag(H)
                ![gama] = 17.1382 + (-0.48513) * tp + (-0.493938) * ti + 2.31266 * i + (8.95959 * 0.00001) *
                  (-0.0754861) * tp * i + (6.575552 * 0.000001) * tp * intmag(H) + (-0.0649648) * ti * i + (2
                .Update
            Next
```

Figure 6. Source code for calculating the objective function Gama

The graph of the values obtained for the intensity of the magnetic field H=54219 is presented in figure 7. The graph for the values obtained for the intensity of the magnetic field H=108809 is presented in figure 8.

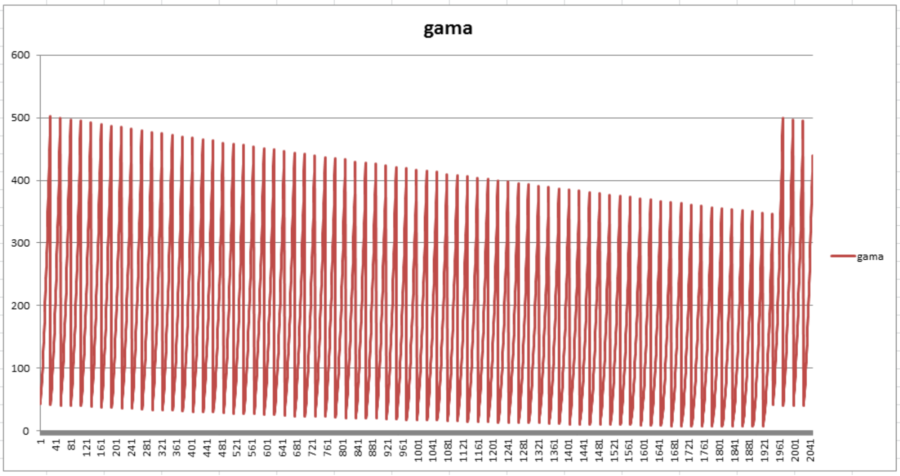

Figure 7. Graph of the values of the objective function gama for H = 54219

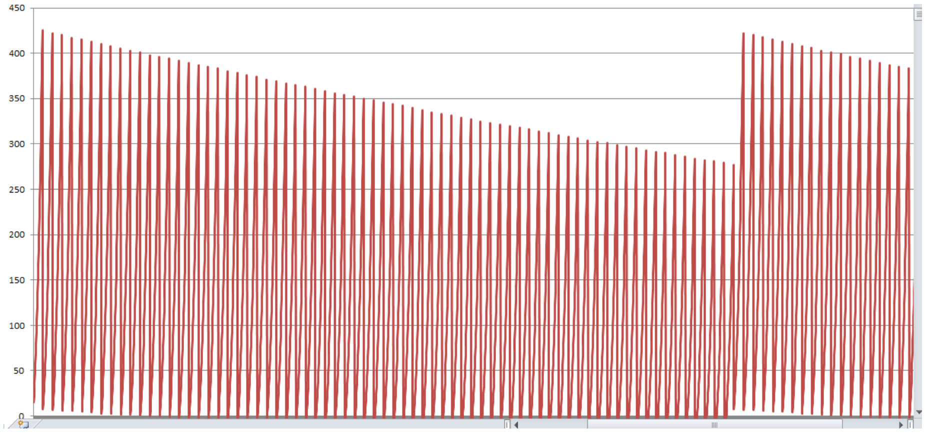

Figure 8. Graph of the values of the objective function gama for H=108809

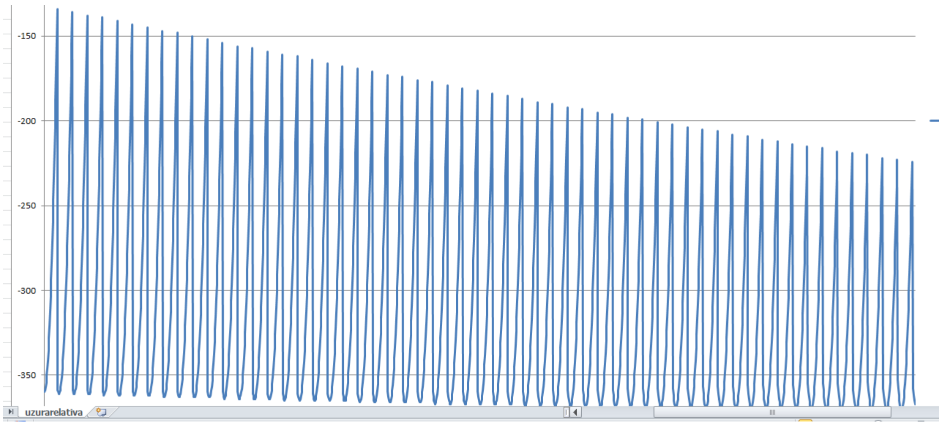

Figure 9. Graph of the values of the objective function gama for H=350000

6 CONCLUSIONS

The designed software allows the calculation of the values of the objective functions, approximately 350000 values for each of the functions.

The programme package generates the corresponding graphs for the calculated values, allowing an intuitive interpretation of the experimental researches done.

7 REFERENCES

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