Using the Factorial Experiment to Optimize the Injection Regime of a Coil Body

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Abstract: *Nowadays, the statistical processing of experimental or observational data is found in all sciences, from social, medical or economic, to engineering, physics, chemistry, biology or agricultural sciences. This research was developed based on a study conducted within a company whose field of activity is the production of parts from various plastics by injection, for the automotive industry and beyond. The advantage of injection molding is the possibility of obtaining objects with complicated shapes and different sizes, from a very wide range of polymers. The operations are automatic and the machines have a high efficiency. The research method approached in conducting the study consist of the factorial experiment. This paper aims to highlight the optimization of the injection regime of a coil body and thus reduce the waste resulting from the injection process within the company.*

Keywords: *injection process, optimization, research method, factorial experiment*

1 INTRODUCTION

The organization in which the research was conducted has as field of activity, the realization of parts from various plastics by injection for the automotive, electronics and electrical industries, followed by the production of stationery.

The organization is certified according to ISO 9001 standards, by TÜV-Thüringen and TS 16949, specific to suppliers in the automotive industry.

Among the products and services offered by the company are:

- connectors and components of electromagnets useful in automated systems in the field of electronics and electrical engineering;
- household appliances - sockets, multiple sockets, switches, diverters, etc.;
- electromagnets with applicability in the automotive industry;
- stationery - rulers, squares, reporters, writing holders, document trays, upright holders, CD / DVD holders, clipboards, folders, organizers;
- promotional items - keychains, pens, rosters, other products that are part of the classic kits of promotional items;
- household items - screwdrivers, painting and painting accessories, PVC hoses, sprayers, hangers;
- spare parts in the field of textile industry - funnels, spindles, sliders;
- professional assembly of plastic parts.

The organization uses a wide range of plastics, such as: PS, PAS, ABS, PP, PE, PA, PBT, PC, PC / ABS, PPS, PPA, Bakelite, Urochem etc.

2 RESEARCH METHODOLOGY

Currently, the statistical processing of experimental or observational data is found in all sciences - from social, medical or economic, to engineering, physics, chemistry, biology or agricultural sciences [1, 2].

Science and technology use the notion of model in two ways:

- The material model, which is represented by an auxiliary object with which the original object is replaced in the experimentation process;
- The abstract (ideal) model, which is represented by a series of quantities with the help of which the object subject to research can be characterized, from certain points of view.

One of the most widespread models of representation of the object subject to research is the one introduced by cybernetics, in the form of inputs-outputs [3].

Input quantities are called independent variables or influencing factors [4, 5].

Output sizes are called objective functions, response functions, or dependent variables [6].

Cause-effect functional links are considered to exist between the two categories of variables [2, 3].

The quantitative description of the phenomena or processes is made with the help of mathematical models associated with them which explain with the help of mathematical relations the functional links between the influencing factors and a certain objective function, in the form of a regression equation [5, 6].

In experimental modeling, two other strategies are known, namely the classical strategy (Gauss-Seidel) and the factorial strategy (Box-Wilson) [1, 2].

The (modern) factorial strategy is characterized by the slogan “all factors at every moment”, the factorial experiment being characterized by the fact that at each experimental attempt the value of all influencing factors changes [7, 8].

The specificity of factorial experiments stems from the fact that they simultaneously study the effects caused on an objective function by all levels of all influencing factors [1, 2].

In experimental modeling, as a rule, a certain form of the mathematical model is accepted, which is considered to best approximate the real model and the development of the experiment will provide the data necessary to explain the model [9, 12].

The main features of the factorial strategy are the following [1,10]:

- progressive acquisition of information following the performance of experiments, with the

possibility of performing a minimum number of determinations to formulate conclusions;
- obtaining maximum precision for estimating the model, for a required number of measurements;
- providing information on the direction of travel of the determinations to achieve the optimal range of the objective function.

3 CASE STUDY

The injection molding process is the technological process by which the material based on macromolecular compounds, brought into a flow state, is introduced, under pressure, into a forming mold.

After filling the mold, the material is kept under pressure and hardened by cooling in the case of thermoplastics and by heating in the case of thermo reactive polymers [11,12].

The plastic granules in the feed hopper of the injection machine, due to the movement of the feed piston, fall into the cylinder, being placed in front of the piston in the retracted position.

When it is moved by means of the machine's drive system, the material is compressed in the front area of the cylinder and forced to come into contact with the entire inner surface of the cylinder, heated by electrical resistances, which causes it to pass into the viscos-plastic phase [13].

The torpedo placed concentrically with the injection cylinder contributes to the thermo-plasticization process, which homogenizes the temperature of the melting material and reduces the passage section of the material, increasing the internal frictions of the viscous fluid [14].

These speeds up the process of reaching the flow temperature, respectively the temperature at which the injection of the material into the mold can take place.

The material, in the form of a viscous and relatively homogeneous melt, is injected through the injection head, nozzle and injection mold of the mold into its cavity.

In contact with the cold walls of the mold, the melt suddenly solidifies, taking the shape of the inner walls of the mold cavity.

After cooling the part, the mold opens and the part is removed with the help of the throwing system [14].

The advantage of injection molding is the possibility of obtaining objects with complicated shapes and different sizes, from a very wide range of polymers.

The operations are automatic and the machines have a high efficiency.

This scientific research aimed to optimize the injection regime of a coil body and thus reduce the waste resulting from the injection process.

Table 1. The matrix related to the factorial experiment

Subject number	Average x_0	Levels of influencing factors				y [%]
		x_1	x_2	x_3	x_4	
1	+1	-1	-1	-1	-1	y_1
2	+1	+1	-1	-1	-1	y_2
3	+1	-1	+1	-1	-1	y_3
4	+1	+1	+1	-1	-1	y_4
5	+1	-1	-1	+1	-1	y_5
6	+1	+1	-1	+1	-1	y_6
7	+1	-1	+1	+1	-1	y_7
8	+1	+1	+1	+1	-1	y_8
9	+1	-1	-1	-1	+1	y_9
10	+1	+1	-1	-1	+1	y_{10}
11	+1	-1	+1	-1	+1	y_{11}
12	+1	+1	+1	-1	+1	y_{12}
13	+1	-1	-1	+1	+1	y_{13}
14	+1	+1	-1	+1	+1	y_{14}
15	+1	-1	+1	+1	+1	y_{15}
16	+1	+1	+1	+1	+1	y_{16}

Given that the injection process results in a significant percentage of waste, which without being considered as a final loss (due to their recycling) leads, however, to additional energy and labor consumption, it is necessary that, in addition to other technical measures, organizational, to proceed to the study of the quality of the manufacturing process, which would allow, finally, the optimization of the working regime and, implicitly, the reduction of waste [15].

In carrying out this case study, the method of the factorial experiment with 4 influencing factors will be used.

The 4 influencing factors that act on the 2 objectively considered functions are the following:

x_1 - mold temperature [ºC];

x_2 - injection speed [cm/s];

x_3 - holding pressure [barr];

x_4 - injection time [s].

The 2 objectives considered are the following:

y_1 - finished product size (coil body size) [mm];

y_2 - the roughness of the finished product [µm].

The matrix - program for a complete factorial experiment using notation in standard order can be rendered as follows in table 1.

The results of the measurements performed on a batch of parts subjected to the injection process were recorded in Table 2.

Table 2. Measurement results

No.	Mold temperature [ºC]	Injection speed [cm/s]	Holding pressure [Barr]	Injection time [s]	Coil body size [mm]	Coil body roughness [µm]
1	180	40.000	80.000	20.000	27.050	2.000
2	300	40.000	80.000	20.000	27.020	1.500
3	180	50.000	80.000	20.000	27.260	2.000
4	300	50.000	80.000	20.000	27.220	1.500
5	180	40.000	200.000	20.000	27.220	2.500
6	300	40.000	200.000	20.000	27.020	1.500
7	180	50.000	200.000	20.000	27.490	2.500
8	300	50.000	200.000	20.000	27.290	2.000
9	180	40.000	80.000	45.000	27.220	1.500
10	300	40.000	80.000	45.000	27.420	2.500
11	180	50.000	80.000	45.000	27.320	2.000
12	300	50.000	80.000	45.000	27.200	1.500
13	180	40.000	200.000	45.000	27.460	2.500
14	300	40.000	200.000	45.000	27.500	1.500
15	180	50.000	200.000	45.000	27.730	2.000
16	300	50.000	200.000	45.000	27.830	1.500

4 RESULTS AND DISCUSSIONS

Following the analysis of the data presented in table 1 and 2, a series of aspects are found:

- the temperature of the mold reaches the maximum value in the value range of 240 ºC;
- the maximum value of the injection speed is 45 cm / s;
- the holding pressure reaches the maximum level at the value of 140 barr;
- the injection time shows that the maximum value of the time is in the range (32; 34];
- the size of the piece reaches the maximum value in the area between (27.3; 27.4);
- the roughness of the piece highlights the fact that it is maximum in the range (1.9; 2].

The higher the mold temperature and injection speed, the larger the part size is.

Figure 1 shows how the part size increases as the mold temperature increases and the injection speed decreases.

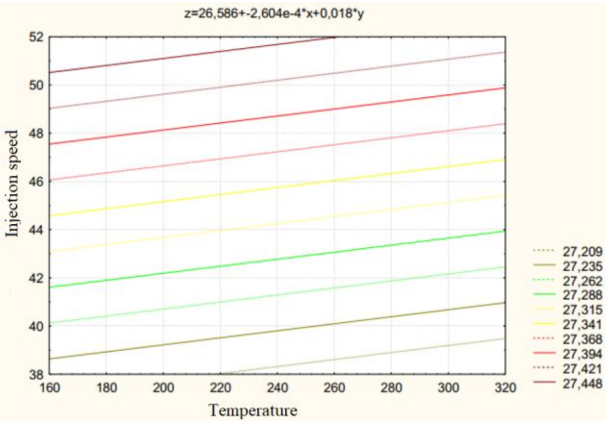

Fig. 1. 3D Contour plot – part dimension according temperature versus injection speed

Figure 2 shows that the part size is larger when the mold temperatures and holding pressure have minimum or maximum values.

As the temperature increases and the holding pressure decreases, so does the size of the part.

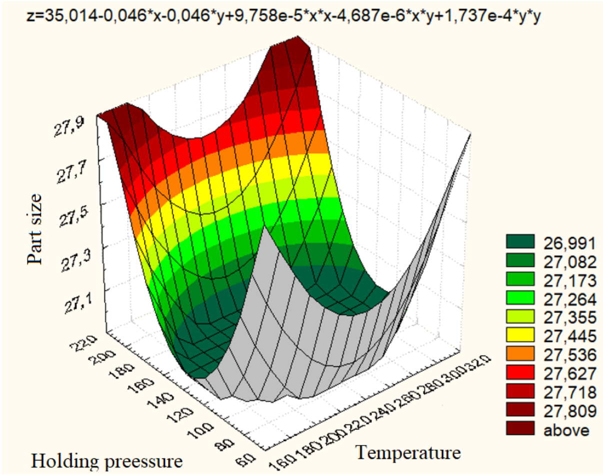

Fig. 2. 3D Surface plot–part dimension according temperature versus holding pressure

Figure 3 shows that the part size is above the maximum value when the injection time and mold temperature reach the maximum value.

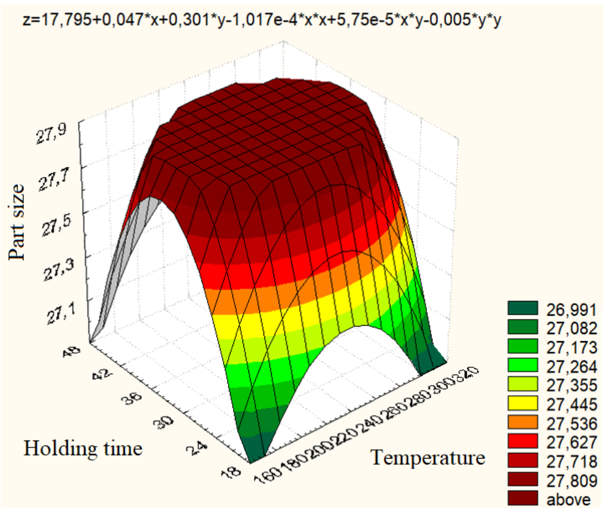

Fig. 3. 3D Surface plot–part dimension according temperature versus hold time

The part size increases proportionally to the temperature and decrease with the injection time and becomes maximum as the injection speed increases.

When the injection speed is maximum, the part size is also maximum.

At the same time, analyzing the results presented in table 2, it is also found that the size of the part increases proportionally to the injection speed correlated with the holding temperature; increases proportionally to injection speed and injection time.

The part size reaches the maximum value at the extremes of the holding pressure and the mold temperature.

The graph of Figure 4 shows that as the mold temperature increases and the holding pressure decreases, the part size becomes larger.

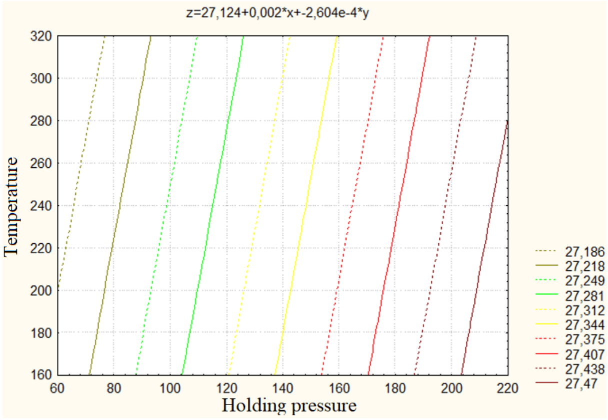

Fig. 4. 3D Contour plot –part dimension according temperature versus holding pressure

At the maximum injection speed value, the part size also reaches the maximum value.

Therefore, the part size increases proportionally to the injection speed and holding pressure.

A maximum part size is also recorded when the injection time is maximum, and with increasing injection time and holding pressure, the part size also increases.

Figure 5 shows that the part size evolves proportionally to the injection time and the mold temperature.

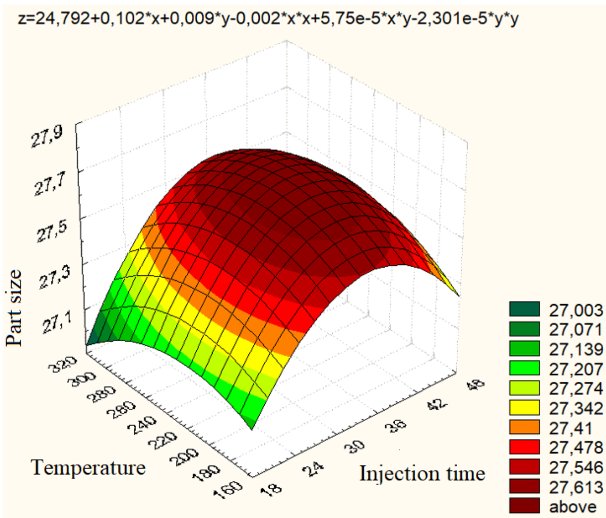

Fig.5. 3D Surface plot–part size according temperature versus injection time

As the mold temperature increases and the injection time decreases, the part size becomes larger. The part size reaches the upper value when the injection speed evolves to the maximum value. At the same time, the part size increases with the injection time and injection speed and, the part reaches a maximum size when the injection time registers a maximum value.

The size of the part increases with increasing injection time and holding pressure.

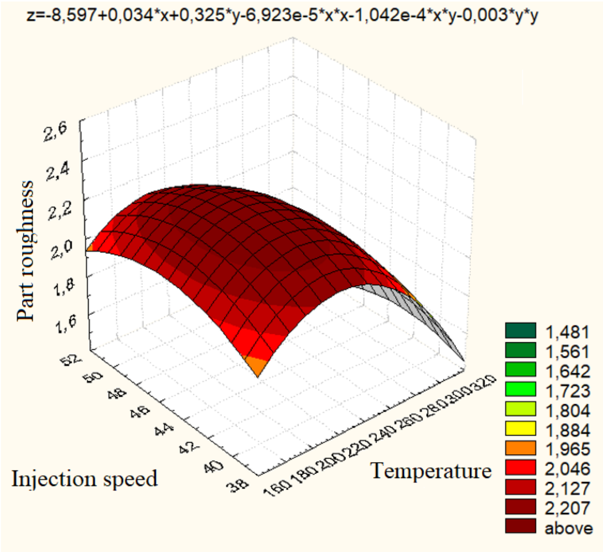

Fig.6. 3D Surface plot–part roughness according temperature versus injection speed

Regarding the roughness in figure 6 it is observed that we have a product with a higher roughness as the injection temperature and speed are high.

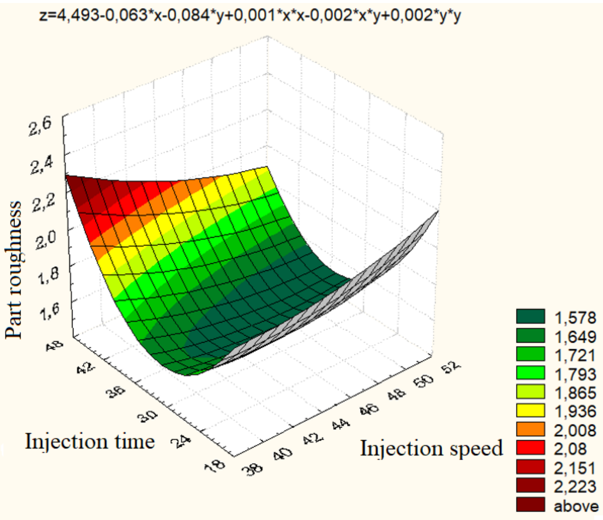

Fig.7. 3D Surface plot–part roughness according injection time versus injection speed

The roughness of the part increases with the injection speed and the temperature of the mold and records low values when the holding pressure increases. As the mold temperature increases and the holding pressure decreases, the workpiece roughness increases.

Therefore, the roughness of the part evolves inversely with the mold temperatures and the injection time; increases when the injection speed and mold temperature are low, and as the temperature and injection speed increase, the roughness of the part also increases.

The roughness of the product increases proportionally to the injection speed and decrease with the holding pressure.

Figure 7 shows that the resulting parts have a high roughness when the speed is low and the time increases.

The roughness of the part increases with increasing injection time and injection speed and reaches the maximum value at the extremities of the holding pressure and the mold temperature.

The roughness of the product increases proportionally to the injection speed and holding pressure.

The roughness of the part is direct proportionally to the injection time and inverse proportionally to the holding pressure.

The roughness increases with increasing injection time and decreases with increasing mold temperature.

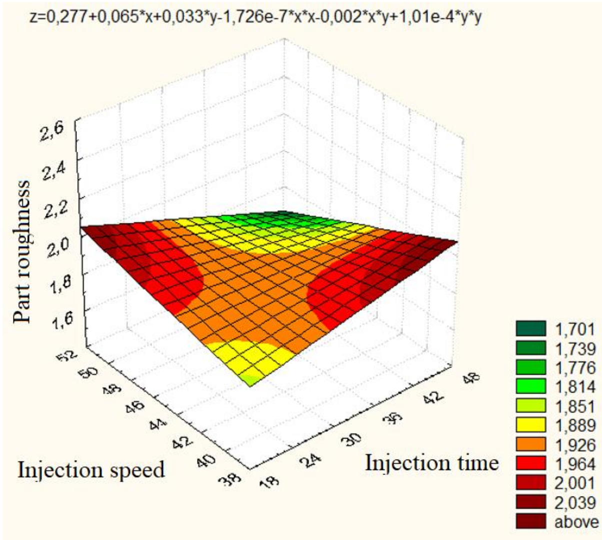

Fig.8. 3D Surface plot–part roughness according injection time versus injection speed

The roughness evolves in the same direction as the injection time and the injection speed (figure 8).

The roughness decreases as the holding pressure increases and increases as the injection time increases.

5 CONCLUSIONS

The second-degree polynomial model corresponding to each graph presented, obtained as a result of performing the factorial experiment is adequate to estimate the response area corresponding to the investigated field, as a result can be obtained with a good estimate of the value of material loss.

Given the existence of random measurement errors, the modern experimentation strategy, applied with the help of factorial experiments, is the optimal experimentation strategy, and the factorial experimentation program is an optimal experimentation plan.

In order to obtain the best possible value for material losses, it is necessary to assimilate the products on the market in the shortest possible time.

Following the factorial analysis, information was obtained on the direction of movement of the determinations in order to achieve the optimal range of objective functions.

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