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HYPOTHESIS TESTING TO CONFIRM THE INFLUENCE OF TECHNOLOGICAL PARAMETERS ON POOR QUALITY PRODUCTION

TESTOWANIE HIPOTEZ DOTYCZĄCYCH WPŁYWU PARAMETRÓW TECHNOLOGICZNYCH NA JAKOŚĆ PRODUKCJI

This report addresses some chosen statistical methods that could be used to confirm and set up the required functions of technology in foundry companies where parts are cast by the low-wax casting method, whereas these chosen statistical methods are intended to reduce poor quality of produced parts. This research was made on a practical example. Utilization of hypothesis testing methods was examined in order to confirm technological parameters having some influence on the products quality. The data were compared before and after the implementation of changes aimed at reduction of poor quality produced parts in the wax department. The results confirmed that the implemented change had a statistically conclusive influence.

Keywords: quality, statistically conclusive influence, hypothesis testing

Artykuł przybliża niektóre wybrane metody statystyczne, które można wykorzystać w celu sprawdzenia ustawień wymaganych funkcji w technologii odlewania metodą wosku traconego, do zmniejszenia wad produkcji. Badania przeprowadzono na konkretnym przykładzie. Zbadano wykorzystanie metod testowania hipotez w celu sprawdzenia parametrów technologicznych wpływających na jakość odlewów. Porównano dane przed i po wprowadzeniu zmian w celu ograniczenia wad produkcji w dziale woskowni.

Wyniki potwierdziły, że wprowadzona zmiana miała statystycznie udokumentowany wpływ.

1. Introduction

The company CIREX s.r.o. is a modern foundry producing castings made of steel. They are manufactured by precision casting into shell moulds using investment wax patterns. It produces high-quality components for the automotive, technology and machine-building industries. One of the most important areas of the company development is quality control of production, which is undergoing a continuous phase of permanent improvement since establishment of the branch in the Czech Republic in 1993.

2. Current state of control of poor quality production in the foundry producing steel castings – CIREX s.r.o.

Control of poor quality production, which includes daily inspection of the entire production flow, is the task of all company workers, who can affect this area in any degree. Information about the achieved poor quality production are important not only for the manufacturer, it is also sensitive information especially for the customer. The current principle of control of poor quality production in the company CIREX begins at recording of the occurrence of individual pieces of castings at in-process production stages, such as production of wax patterns, department of processing of ceramics, and its ends by assessment of the quality of castings by identification and summarization of casting defects in the given production series. The task of the teamwork at the subsequent regular analyses of the results of poor quality production consists particularly in exploration of the causes of specific defects. Presentation of defects not only in terms of the number of pieces of castings, but also from the viewpoint of the economic evaluation is matter of course. Visualisation presented for example by use of the Pareto diagram need not be directly proportional to the number of pieces of casting from the poor quality production. On the basis of statistical evaluation for support of enhancement of quality of steel castings technological changes are for precisely defined types of products proposed and then implemented at concrete production operations. These groups of products are subjected to special analysis and it may be decided about practical implementation of the recommended technological changes from trial production. After repeated evaluation these final recommendations are then implemented into the serial production.

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3. Theoretical bases of testing of statistical hypothesis

Statistical hypothesis is an assumption of the probability distribution of one or more random variables. It is a pre-supposition of parameters of random variable in the basic file, or it may be related to the law of distribution of random variable. Based on the results determined from a random selection the decision is taken whether to reject or to accept the test of statistical hypothesis [1]. We describe as "zero hypothesis" the assumption, which we want to verify and we denote it as H_0. The test will decide, whether to reject it or to accept it. An alternative hypothesis H_1 is a contrary to the zero hypothesis. It is accepted only in the case that the zero hypothesis is rejected [2].

3.1. General principles of testing

At first we choose the testing criterion T, which is a random quantity from the viewpoint of probability. The calculated T is a realisation of this random quantity and it is then compared to the critical values.

Testing procedure:

- formulation of a zero H_0 and of an alternative hypothesis H_1.
- calculation of the testing criterion T.
- finding of the critical value K.
- comparison of K and T – rejection or acceptation of H_0.

Field of values of the random variable T is divided by the critical value K into two parts – the critical field W and the field of acceptation V.

Decision on acceptation or rejection:

If T ϵ W, then H_0 is rejected, if T ϵ V, then H_0 is accepted.

At decisions it is necessary to take into account that we can make two mistakes:

1. *Mistake of the first kind* – the valid hypothesis is rejected. Probability of mistake of the first kind *p* or alpha (= level of significance) is expressed by the equation (1):

$$p = P(T \epsilon W - H_0) \tag{1}$$

2. *Mistake of the second kind* – the non-valid hypothesis is accepted. Probability of mistake of the second kind beta is expressed by the probability condition of equation (2):

$$ß = P(T \epsilon V - H_1) \tag{2}$$

Fig. 1 presents graphical visualisation of probability of both possible mistakes.

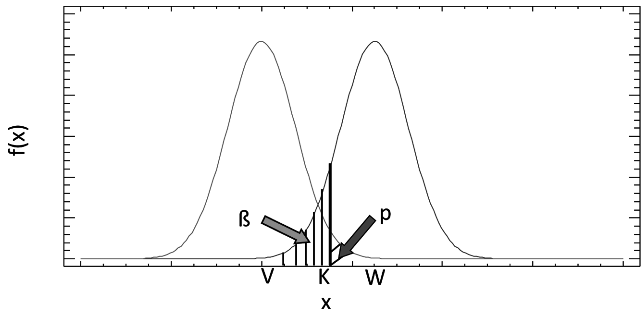

Fig. 1. Probability of mistake of the 1^{st} and 2^{nd}kind

It is possible to express ß as (3):

$$ß = 1 - P(T \epsilon W - H_1) 1 - ß = P(T \epsilon W - H_1) \tag{3}$$

Probability according to the relation Eq. (3) expresses the force of the test, i.e. the probability that the hypothesis H_0 will be rightly rejected [2].

3.2. Test of the significance of two variances (F-test) [2,3]

It is necessary to perform first the test of the significance between two variances (F-test), the result of which leads to selection of the correct type of t-test.

Premises: Two selections are given with the range n_1, n_2 and variances s_1^2, s_2^2 selected from two basic files with distributions N $(\mu_1 \sigma_1^2)$ and N $(\mu_2 \sigma_2^2)$.

Zero hypothesis: H_0: $\sigma_1^2 = \sigma_2^2$ Alternative hypothesis: H_1: $\sigma_1^2 \neq \sigma_2^2$

Testing criterion Eq. (4):

$$T = \frac{S_1^2}{S_2^2} \tag{4}$$

has Fischer's distribution $F_{(n_1-1,\, n_2-1)}$. The critical value is determined from tables of the Fischer's distribution for n_1 - 1 and n_2 - 2 degree of freedom and level of significance p.

If T> $F_{(n_1-1,\, n_2-1)}$ (p), then H_0 is rejected and H_1 is accepted.

3.3. Test of significance between two average values (two-selection t-test) [3]

It is a test, which is used for evaluation of experiments, where we do not know the average value of the basic file. We compare only 2 files of selection data. The data may be represented either by two measurements performed repeatedly in one group of individuals (typically measurement before and after the given experiment), or by two independent groups of measurement.

The zero hypothesis is from the two-selection t-test the following: H_0: $\mu_1 = \mu_2$

Alternative hypothesis: H_1: $\mu_1 \neq \mu_2$

3.3.1. F-test, zero hypothesis is accepted

In the case that at the F-test the zero hypothesis is accepted (H_0: $\sigma_1^2 = \sigma_2^2$), the testing criterion is called according to the Eq. (5):

$$T = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{(n_1 - 1)\, S_1^2 + (n_2 - 1)\, S_2^2}} \cdot \sqrt{\frac{n_1 \cdot n_2 \cdot (n_1 + n_2 - 2)}{n_1 + n_2}} \tag{5}$$

{*Równania zredagowane niezgodnie z wytycznymi, równania w nowym wierszu*}
where $\bar{X}_1, \bar{X}_2$....average value,$S_1^2, S_2^2 S_1^2$, S_2^2....sample variance, n_1, n_2....ranges of the 1st and 2nd selection. Critical value (p) is determined from tables of the Student's distribution for $n_1 + n_2 - 2$ degrees of freedom and level of significance *p*. If-T->(p), then H_0 is rejected and H_1 is accepted.

3.3.2. F-test, zero hypothesis is rejected

In the case that the zero hypothesis is rejected at the F-test (H_0: $\sigma_1^2 \neq \sigma_2^2$), then the testing criterion is calculated according to the Eq. (6, 7):

$$T = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{V_1 + V_2}} \tag{6}$$

where

$$V_i = \frac{S_i^2}{n_i - 1} \tag{7}$$

$$i = 1, 2.$$

The critical value K is calculated according to the Eq. (8):

$$K = \frac{V_1 . t_{n_1-1}(p) + V_2 . t_{n_2-1}(p)}{V_1 + V_2} \tag{8}$$

$t_{n_1-1}(p), t_{n_2-1}(p)$ is determined from tables of the Student's distribution for $n_1 - 1$ and $n_2 - 2$ degrees of freedom and level of significance *p*.

If -T->K, then H_0 is rejected and H_1 is accepted.

It is not necessary to obey the assumption that both selections must come from normal distribution. The T- test is calculated with use of averages of both selections and they have approximately normal distribution.

4. Methodology of solution of statistical significance of tests performed at production process

For our solution we chose by use of the Pareto analysis the castings, where occurrence of rejects varied with jumps and where also the financial loss was high. A detailed inspection of production at each production stage was proposed. A basic analysis of produced poor quality pieces from the wax shop was performed as first, and it is shown in Tab. 1. The values presented in table confirmed the jump shift of production quality. In one production batch it was possible to produce 4 pieces of poor quality patterns and in another batch even 322 pcs.

TABLE 1

Basic values of statistical analysis

Total quantity	103 368 pcs
Poor quality production – non-burnt wax	4 469 pcs
Average value	93.10
Standard deviation	72.55
x_{max}	322 pcs
x_{min}	4 pcs

On the basis of unstable results from the wax shop we decided to focus on this stage of production. It concerned mostly "wax defects" both on the wax patterns, which were captured already during the production itself at the injection moulding machine, as well as in the final castings. Our attention was first focused on control of functionality of the injection moulding machine. At present the method of investment casting consists of production of the pattern with the gating from a wax material, which melts at low temperature. The pattern is dipped into the molten refractory ceramic material and thus coated with such ceramic coating. After solidification of the binder the pattern is molten away by heating in the annealing furnace to an appropriate temperature. The created mould is then filled with molten metal and the casting is after cooling down rid of ceramic mould partly by knocking and blasting [4]. Numerous factors enter each of this gradual process, for which it is not possible to determine without use of statistical methods, whether they influence it statistically significantly or not.

4.1. Main parameters of production technology of injection moulding machine [5]

The cycle of injection of wax material requires setting of the following parameters:

– temperature of container, heat exchanger, nozzle, cooling plates;
– filling pressure, pressure for switching, thrust;
– injection speed;
– time of filling of mould with wax, time of pressure drop.

It is possible to register from the injection moulding machine the values of filling pressure, wax pressure, time of filling. *The filling pressure* is pressure of oil acting on hydraulic cylinder that is necessary for filling of the mould. *Wax pressure* is the pressure in the inlet hose for wax at the entry to the mould nozzle. If this sensor registers the pressure set for switching during filling of the mould, it sends signal to the PLC/wax cylinder, so that filling pressure is switched to the thrust pressure. The time between the initial pressure for filling the mould (0 sec.) and achievement of the pressure for switching, is the *time of filling.* The start of the injection cycle is the start of filling of the mould with wax. At the end of the injection cycle the system must be switched to the time of pressure drop. The mould must remain closed until expiration of the time of pressure drop. Figure 2 shows the functional diagram of wax injection moulding machine. Standard example of time period of the injection cycle in dependence on wax pressure in the inlet hose at entry into the mould nozzle is shown in Fig. 3.

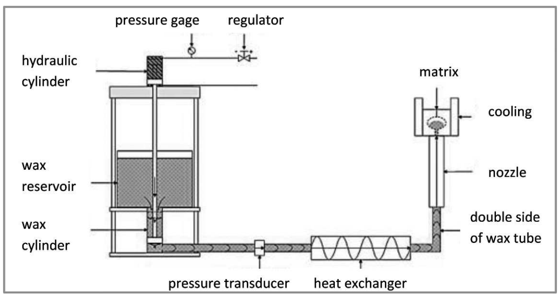

Fig. 2. Wax injection moulding machine

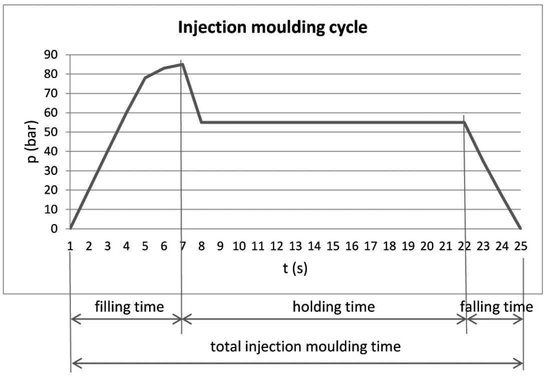

Fig. 3. Injection moulding cycle

4.2. Analysis of function parameters of the injection moulding machine

Analysis of injection moulding machine function, particularly time of filling of the mould cavity, time of thrust and drop of pressure showed non-standard operational parameters. It can be seen from graphical presentation in Fig. 4, illustrating the injection cycle, that start and switching are not functional. On the other hand the injection cycle presented in Fig. 5 is correct. The correct injection moulding cycle is shown in the next Fig. 5. In the *first phase* in the function of time of filling the mould it is filled at certain time unit. The *second phase,* i.e. thrust – is necessary for ensuring the dimensions of future casting. In the *third phase,* i.e. function of pressure drop the injection moulding cycle is completed.

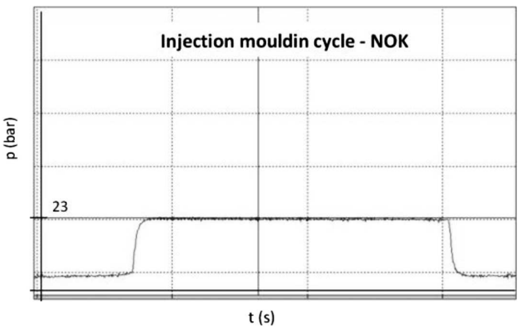

Fig. 4. Injection moulding cycle – NOK

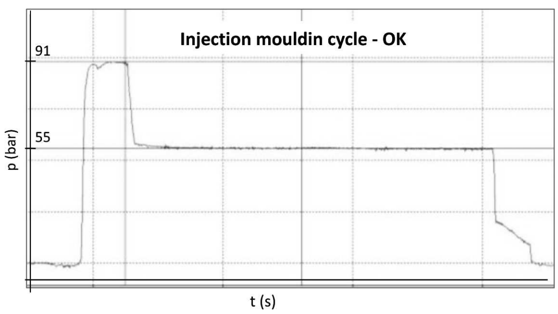

Fig. 5. Injection moulding cycle – OK

On the basis of results of overall analysis of technological production process during its individual phases on the injection moulding machine it was decided to make its total repair.

4.3. Statistical evaluation of importance of implemented correction action

Verification and evaluation of importance of the implemented correction action concerning the thrust function on the injection moulding machine was made with use of the t-test in order to determine the significance of difference between two average values. With use of statistical software Statgraphics we performed an analysis of wax shop operational data and statistical evaluation of significance of the state before and after the overall repair of the injection moulding machine, namely production phase concerning thrust acting on the product, which was manufactured at this equipment in a long run and in regular intervals. Tab. 2 presents the obtained results.

TABLE 2
Analysis of data from the wax shop

	before repair (%)	after repair (%)
average	4.23	7.53
standard deviation	1.38	1.34
variation coefficient	32.83	17.81
minimum	2.40	6.58
maximum	5.75	8.48
range	3.35	1.89
number of produced pieces	57 600	23 680

Individual values are given in percents of rejects of the selected product. At the first glance the average value of scrap factor is higher after repair of the injection moulding machine, however, the value of range of the achieved results is lower by more than 50%. This indicates correctness of the implemented correction action aimed at repair of the injection moulding machine, or stabilisation of the production process. Tab. 3 presents summarised achieved results of testing the significance of difference between two average values with use of two-selection t-test.

TABLE 3
Statistical evaluation of significance of results obtained in the wax shop

<table>
<tr><td>Signature: xxxxxxxxx</td><td>before repair</td><td>after repair</td><td colspan="2" rowspan="3">WM XXXX
Date of evaluation : 12. 11. 2013
Result: STATISTICALLY SIGNIFICANT INFLUENCE</td></tr>
<tr><td>average</td><td>4,23</td><td>7,53</td></tr>
<tr><td>standard deviation</td><td>1,38</td><td>1,34</td></tr>
<tr><td>F-test</td><td colspan="2">$T = \frac{S_2^2}{S_1^2}$</td><td>t-test</td><td>$T = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{(n_1-1)\,S_1^2 + (n_2-1)\,S_2^2}} \cdot \sqrt{\frac{n_1 \cdot n_2 \cdot (n_1+n_2-2)}{n_1+n_2}}$</td></tr>
<tr><td>F-test</td><td colspan="2">T> $F_{(n_1-1,\,n_2-1)}$ (p)</td><td>t-test</td><td>$|T| > t_{n_1+n_2-2}$ (p)</td></tr>
<tr><td>F-test</td><td colspan="2">4,07<224,59</td><td>t-test</td><td>2,86>2,57</td></tr>
<tr><td>F-test</td><td colspan="2">H_0accepted: $\sigma_1^2 = \sigma_2^2$</td><td>t-test</td><td>H_0rejected: $\sigma_1^2 = \sigma_2^2$</td></tr>
</table>

Test of statistical significance of difference between two average values has proved that repair of the thrust function on the injection moulding machine had statistically significant influence on the whole production process of the steel foundry.

5. Conclusions

For determination of correctness, effectiveness and efficiency of the implemented correction action in the wax shop we used the t-test with determination of significance of difference between two average values. Before the calculation of the t-test it was necessary to decide, which of two possible kinds should be chosen. We used for this solution the F-test.

Result of the t-test has proved unequivocally, that repair of the thrust function on the injection moulding machine had statistically significant influence on the scrap factor of the given product. On the basis of obtained results of used hypotheses we decided to apply this method also for other projects at implementation of changes of production technology and for evaluation of their significance. For purposes of operational practice we created in the Excel program a template, which would make it possible to evaluate individual interventions into the production technology immediately after obtaining the achieved results. The results will be entered into the exactly defined cells and thanks to the generated formulae we will immediately obtain an information about fluctuation at production, or on the other hand, about successful implementation of the given action into the production technology. The pre-requisite will be an exact definition of the rules for this method. It is not expected that direct interventions into the production technology will be made on the basis of correct results of the t-test. The obtained results will be, however, an important indicator of the state of running production process.

REFERENCES

[1] M. M e l o u n, J. M i l i t k ý, Statistická analýza experimentálních dat, Praha (2004).
[2] J. T o š e n o v s k ý, D. N o s k i e v i č o v á, Statistické metody pro zlepšování jakosti, Ostrava (2000).
[3] J. T o š e n o v s k ý, M. D u d e k, Základy statistického zpracování dat, Ostrava (2000).
[4] J. D o š k á ř, Přesné lití do keramických forem, Praha (1961).
[5] R. L a k o m á, L. Č a m e k, In: 22nd International Conference on Metallurgy and Materials, p. 40, Tanger, Brno (2013).

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