QUALITY ASSURANCE OF THE PRODUCTION PROCESS PARAMETERS WITH HELP OF STATISTICAL METHODS IN THE AUTOMOTIVE INDUSTRY USING THE MONTE-CARLO METHOD

GYÁRTÁSI FOLYAMAT-PARAMÉTEREK MINŐSÉGÉNEK BIZTOSÍTÁSA STATISZTIKAI MÓDSZER SEGÍTSÉGÉVEL AZ AUTÓIPARBAN MONTE-CARLO MÓDSZER ALKALMAZÁSÁVAL

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Abstract

The production processes, or their effectiveness is influenced and determined by the process parameters of the individual processes, the result of which will be given by the characteristics of the finished product, and thereby (also) sold to the customer, so to speak. However, in order to be effective, it is worth predicting the expected result in the light of experience, or in the knowledge of customer requirements. An essential condition for effective forecasting, i.e. ensuring quality at the expected level, is not only to know it well, but also to be proficient in the applied (production) technology, the operation of the machines, as well as how changes in individual parameters induce the result (finished product), i.e. how the data are related to each other, how they correlate with each other. In the following, I will talk about the specific production area, as well as the related technology, which was the subject of the investigation. This is followed by method and material. And as a result of all this, I will explain the essence of the method in the light of the circumstances of the present use.

Keywords

quality, heat-treatment, statistical methods, risks, Monte-Carlo simulation, safety

Absztrakt

A gyártási folyamatokat, ill. azok eredményességét az egyes folyamatok folyamatparaméterei befolyásolják, határozzák meg, amelynek eredőjét a késztermék jellemzői fogják adni, s ezáltal úgymond eladni (is) a vevő számára. Ahhoz azonban, hogy a hatékonyak tudjunk lenni, érdemes előre jeleznünk a várható eredményt a tapasztalatok tükrében, ill. a vevői követelmények ismeretében. Az eredményes előrejelzés, azaz az elvárt szinten történő minőség biztosításának elengedhetetlen feltétele, hogy nem pusztán jól ismerjük, de jártasok legyünk az alkalmazott (gyártás)technológiában, a gépek működésében, valamint abban is, hogy az egyes paraméterek változásai hogyan indukálják az eredmény (késztermék) minőségét, azaz az adatok milyen kapcsolatban vannak egymással, azok hogyan korrelálnak egymással. A következőkben szót ejtek az adott gyártási területről, valamint a kapcsolódó technológiáról, amely a vizsgálat tárgyát képezte. Ezt követi a módszer és anyag. S mindezek eredményeként a módszer esszenciáját ismertetem a jelen felhasználás körülményei alapján.

Kulcsszavak

minőség, hőkezelés, statisztikai módszerek, kockázat, Monte-Carlo szimuláció, biztonság

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INTRODUCTION

The statistical method presented below has a place in the activities of many manufacturing companies, but the automotive industry is one of the first areas in which such methods may appear in practice, which will later be transferred to other areas as well. Although the method is known in the scientific world, its practical implementation has not really spread in the toolbox of quality assurance, in manufacturing, in the automotive industry.

Naturally, it is a prerequisite to acquire a thorough knowledge of the specific production processes, of the technology and of the specifics as it is essential during the successful application of the method presented below, as well as for defining further conclusions.

In the next chapter, I will mention the literature of the investigated area, and I will also refer to the importance of the antecedents developed in the material and method chapter. In the research results chapter, I prove the usefulness of the method in relation to the given production process. Finally, I will talk about the conclusions.

LITERATURE

Even today, motorized vehicles are of particular importance in all areas of life (e.g. logistics, competitive sports, etc.). And still a significant role and proportion are represented by engines with drives in which the four-stroke spark ignition engine provides its essence. It was Nikolaus August Otto (1832-1891) who invented the four-stroke engine. In internal combustion engines, the camshafts, or more precisely the cams on them, are moved with the help of valves to allow air to be sucked in, or to allow combustion products to be emitted. When the cam on the rotary shaft turns to the valve lifter, it opens the valve by pressing it down. By turning the cam, the given spring resets the valve to its original position. There are two strokes per crankshaft revolution: intake-compression or combustion-exhaust. Said cams, which are responsible for controlling the movement of the valves, are a chrome-alloyed cold-formed tool steel with high wear resistance. This material is usually used to manufacture parts where they will be subjected to heavy stress, pressure, and friction in terms of use. [2] [5] [10]

Only valves are used in internal combustion engines for air intake or for the emission of combustion products. The cam consists of one or more camshafts. In two-stroke engines, the camshaft rotates at the same speed as the crankshaft, while in four-stroke engines, the speed of the camshaft is half the speed of the crankshaft.

The work cycle after which they were named consists of the following four steps:

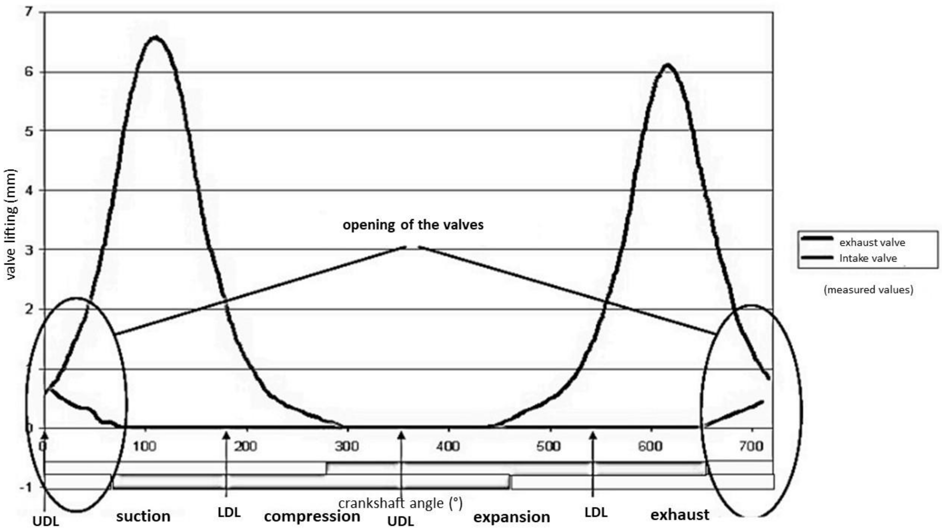

Figure 1.: Valve opening depending on crankshaft position [2]

In the first stage, by utilizing the full amplitude, the piston moving along the stroke increases the volume and creates a pressure drop. Atmospheric pressure air or the gas mixture moves into the lower pressure cylinder with the help of the valve opened by the cam. The piston is then set in motion by the flywheel and piston mechanism. In the second step, the previously mentioned mechanism pushes the piston towards the top deadlock and compresses the gas mixture found in the cylinder. Then, before the end of the compression cycle, the ignition arc ignites the gas mixture in a position corresponding to pre-ignition. In the third step, the burning gas mixture is at a fairly high temperature while its pressure increases. The higher pressure pushes the piston towards bottom deadlock. Thus, it works with the help of the expanding gas and piston and the crank mechanism. And finally, in the fourth stage, the momentum of the mechanism moves the piston in the direction of the top deadlock, so that the combustion product can flow out into the environment to a lesser extent through the open exhaust valves. During the four strokes, i.e. one cycle, the valves must be opened once, so the camshaft turns half as much as the crankshaft, as I mentioned above.

The following control types were used:

- Side valve camshaft
- Overhead camshaft
- Double Overhead camshaft
- Mixed-valve camshaft

In our case, we will examine the double overhead camshaft (DOHC) engine, since the use of our part to be installed on the customer side will be in such a unit. This is the most favourable solution for increasing the speed, because all the structural parts of the cam, except for the valves, perform a circular movement, so no mass forces are generated. In order for this type of arrangement to be the most effective, it is also necessary that the mixture formation and the combustion of the gases take place as quickly and perfectly as possible. (For example, in the case overhead camshaft, the increase in revolutions may be limited by alternately moving valve rockers, valve lifter rods or lifting capitals.) [2]

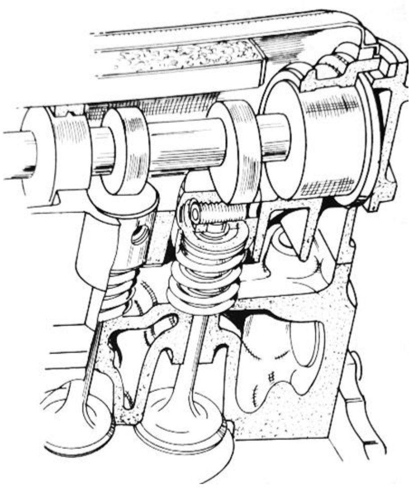

Figure 2.: Detail of a camshaft installation [2]

The valves of the internal combustion engine are moved along the profiled curved bodies formed on the cam (camshaft) - regardless of the engine control. Cam profiles are basically determined by the following aspects:

a) the opening and closing point of the valve due to the gas dynamic effects occurs before or after the deadlock and not at the beginning and end of the cycle
b) the size of the of the base circle radius of the cam (r0) or the camshaft diameter depends on the maximum valve lift height (hmax) at the given control angles
c) the accelerations that occur when opening and closing the valve are particularly important, since - within the opening time - the opening and closing speeds interact synergistically with one another
d) the largest overflow cross-section must be exposed, according to which the goal is for the valve to open as quickly as possible so that the valve rises as high as possible during the given interval
e) although the opening and closing speed should not be too high, as high accelerations and mass forces may stress and damage the control mechanism.

Among these conflicting aspects, it is necessary to find the "golden middle ground", i.e. to use a cam profile that, on the one hand, creates a large flow "cross-section" with not too harmful accelerations, in an effort to avoid excessive loads. However, it must not be forgotten that the rate of valve lift is determined together by the control cam profile and the associated lifting rocker, arm, and base, and it is also possible to test them together.

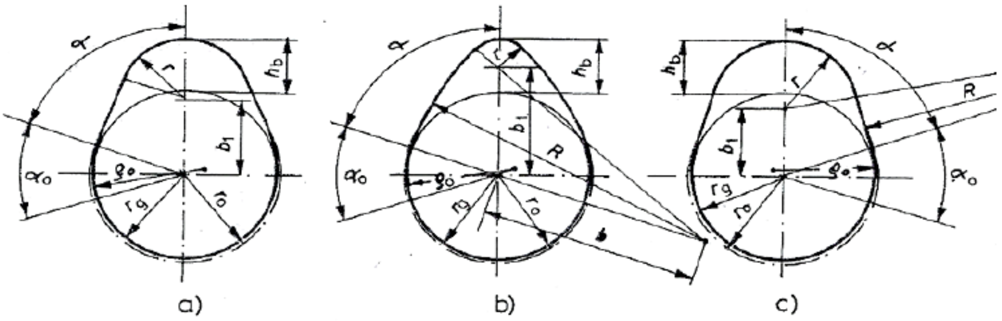

Figure 3.: Basic types of control cams [2]
a) tangential; b) convex-sided circular arc cam; c) concave sided

a) tangential: can be used for larger control angles,
b) harmonic: uniform (sin, cos) phoronomic curves in the case of a flat lifting base,
c) concave-sided: it provides a large control time cross-section for slow motors
 (can only be used with a roller lifter)
 Lifting motion laws: phoronomic curves
 (they depend on the cam profile and the design of the lifting foot): Acceleration, Speed, Stroke

Cam pairs are placed on the intake and exhaust camshafts. The cam pairs are tempered at 100-110° or they are placed according to the firing distance in the firing order of the cylinders. However, another important aspect - in addition to grinding - regarding the durability and load capacity of the cam is the heat treatment (hardening) process.

Since durability, reliability and the life of the product play an important role in the assessment of the added value, in the eyes of the customer, this is why it is necessary to look at some aspects of the heat treatment process in more detail.

Heat treatment is a planned structural transformation process that includes heating, heat retention and cooling, which help to achieve the following properties:

- increasing hardness, wear resistance,
- high surface hardness,
- ensuring a high fatigue limit,
- increasing corrosion resistance,
- increasing heat resistance,
- reducing the stresses in the piece,
- ensuring a uniform grain size.

The heat treatment process consists of the mentioned three stages. By plotting the temperature as a function of time, we get the process diagram of the heat treatment, the stages of which differ in their characteristics [10]:

- The speed of heating is of high importance. It is advisable to slowly heat the alloy steels to the tempering temperature, or the other option to avoid harmful thermal stresses is selective heat treating. The workpiece placed in a warm oven does not heat up evenly to the heat treatment temperature. By definition, the surface heats up faster than the interior of the material. Of course, this temperature difference is insignificant in the case of smaller pieces, which we call thermally thin bodies, and there are thick bodies in which this difference is significant.

- The heat-up rate is the timeframe required to reach the desired temperature on the surface of the workpiece from the start of heating. Furthermore, we can also talk about rewarming or equalization time, by which we mean the time required from reaching the required temperature on the surface to reaching the required temperature in the material core. Thus, the process consists of the heating and the heat-up rate. In heat treatment practice, the heating time must be determined mathematically, but it is calculated based on empirical relationships.
- The heat retention temperature determines the atmosphere. In an oxidizing atmosphere, decarburization is a harmful phenomenon, which means that the carbon is partially or completely burnt from the surface of the steel, so that the hardening cannot provide the desired hardness. In this part of the process, the desired metallurgical processes take place, which determine the duration of heat retention. A shorter time is usually suitable for the allotropic (ferrite-austenite) transformation, but diffusion (cementing, nitriding) transformations can take longer. We try to reduce our heat retention time as much as possible, taking into account the achievement of the goal, of course. The disadvantage of longer heat retention can be that it is expensive on the one hand, and that it promotes the initiation of harmful processes, such as the coarsening of the austenite grains, which can have a negative effect on the mechanical properties.

There are heat treatment processes that differ only in the cooling phase (normalization) and produce material with a different tissue structure and properties. Different cooling speeds can be used in the controlled cooling phase. We have to use a slow cooling process in order to achieve as little stress as possible on the material. If we cool quickly, we prevent the diffusion of individual elements. During the longer cooling period, a temperature difference may develop, which may even cause a crack in the material. Several cooling methods can be used to minimize this (water, oil, salt, metal baths). Blown, stationary (cooling pit) air cooling can be used for slow cooling. Since diffusion processes must be prevented, rapid cooling cannot be avoided in many cases.

In the following, the examined Monte-Carlo method analyses the production process of the induction tempering procedure. Above all, we need a production equipment that ensures stable quality in mass production with the help of an optimized cycle time, in accordance with the principles of reliability and stability, for which regular machine maintenance is also an essential condition. The result of the mentioned induction procedure, taking into account the prescribed requirement, is evaluated by the hardness depth measurement characteristic.

Briefly about induction tempering: if an electrically conductive metal is placed in a coil with an alternating current, an eddy current will be generated as a result of the magnetic field. This eddy produces Joule heat, which heats the metal. Furthermore, if the metal can be magnetized, the loss of magnetization can also generate heat, which accelerates the heating.

Our goal is to achieve the desired outcome as a result of the individual production process steps, and to make the customer satisfied. We have to think backwards, so to speak, about what we have to do at the expected level, in order to achieve the defined goal while minimizing the loss. As I mentioned above, you need to know the production process, i.e. the relationship between our data and data groups. This mentioned correlation study is included in the scientific thesis of Hugyi [5], with an emphasis on regression analysis, which serves as an important input for the results presented in this study.

MATERIAL AND METHOD

Monte-Carlo method is what Pokorádi [8] calls numerical methods for solving mathematical problems that use the modeling of random quantities, and also their statistical evaluation, taking into account their characteristics. The method is widely used for the simulation of possible outcomes of differentiated events and their probabilities, in the case of system excitation parameters with some parametric uncertainty. [7]

The essence of the Monte-Carlo method is to randomly select a value for each uncertain, excited parameter based on the probability distribution. The advantage of the method is that the questions can be answered simply by solving the random numbers quickly and easily. [7]

Before applying the Monte-Carlo method, it is important to check the fit of the data. The purpose of the fit test is to decide, at a given confidence level, whether the random variable from which the statistical sample is taken can be a distribution that can be described by a given distribution function F(x). This distribution can be discrete or continuous, as well as uniform or normal.

I conducted the fit test based on the Kolmogorov test. The Kolmogorov test is used to check whether the distribution function of a given continuous random variable ξ is a given function F(x). First, we prepare the empirical distribution function of the examined random variable ξ, which is denoted by Fn (x) in the case of n observations, i.e. a statistical sample with n elements. The value of the empirical distribution function is the relative frequency of values smaller than x at a given location x. So Fn (x) has a jump of size xi|n for each sample element ξi, where xi is the number of observations of the given value. [4]

In the next step, in the case of the Kolmogorov test, the test statistic can be determined as follows. We calculate the maximum of the difference between the theoretical and empirical distribution functions [4]:

$$\boxed{D_n = \max_x \left| F_n(x) - F(x) \right|;} \tag{1}$$

and then the test statistic:

$$\boxed{\sqrt{n} D_n} \tag{2}$$

which can be shown to correspond to the Kolmogorov function K(z):

$$\boxed{\lim_{n \to \infty} P\left(\sqrt{n} D_n < z\right) = K(z);} \tag{3}$$

For a given confidence level, we find the critical value z, and if the value of the test statistic is smaller than the critical value, then the null hypothesis that the distribution function is F(x) is accepted [4].

RESEARCH RESULTS: HARDNESS DEPTH WITH MONTE-CARLO SIMULATION TO UNDERSTAND ITS DEVELOPMENT

Our null hypothesis is that our data recorded through experience is uniformly distributed. In the case of the Kolmogorov test, as I mentioned above, in order to determine the test statistic, we calculate the maximum of the difference between the theoretical and empirical distribution functions, which, based on the methodology mentioned above, is: 0.1195460277427. Then we get the test statistic value: 0.963811. Since the critical z value at the 95% confidence level is 1.36, and the value of the test statistic is smaller than the critical value, we accept the null hypothesis that the distribution function is F(x). Since the Kolmogorov test confirmed the even distribution of the empirical data, no further fit testing was warranted based on our data set, so I was able to proceed with the application of the Monte-Carlo method.

As the name implies, the Monte-Carlo method means the conscious application of randomness, which is the essence of gambling. The essence of Monte-Carlo algorithms is that we model or perform calculations in such a way that we generate random numbers a large number of times and then substitute them into the mathematical model.

In Microsoft Excel, the RAND() function returns a uniformly distributed random value in the interval [0, 1[. This is the basis of all Monte-Carlo simulations and all other distribution simulations.

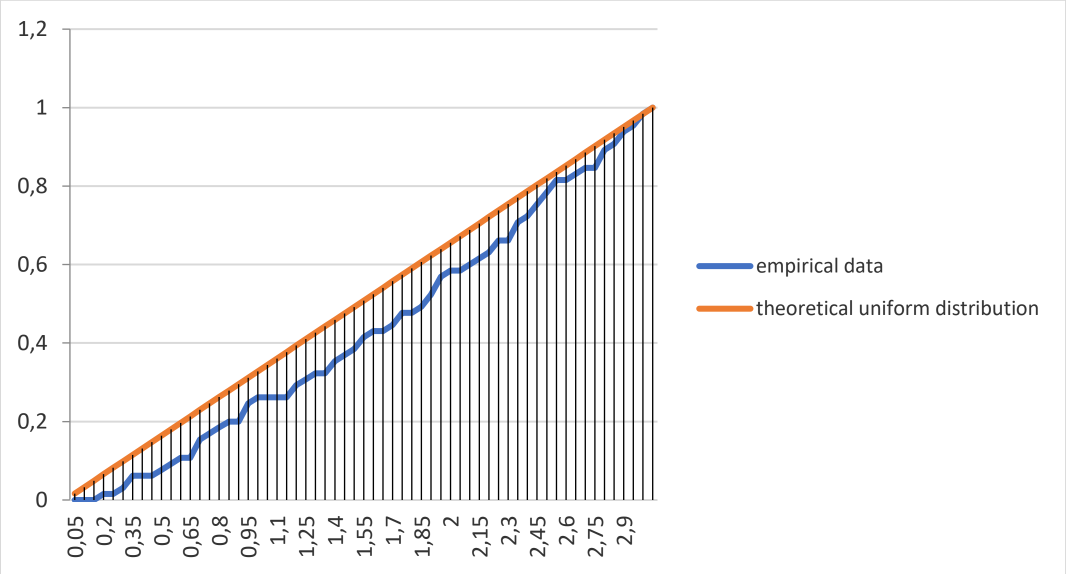

Figure 4.: Fit test based on Kolmogorov test, examining the null hypothesis

Uniform distribution in the interval [a, b[:

$$a + (b - a) \times \text{RAND}() \tag{4}$$

On the previously mentioned production machine, which implements the induction tempering process, the possible energy level for this product can be set to: 450-850.

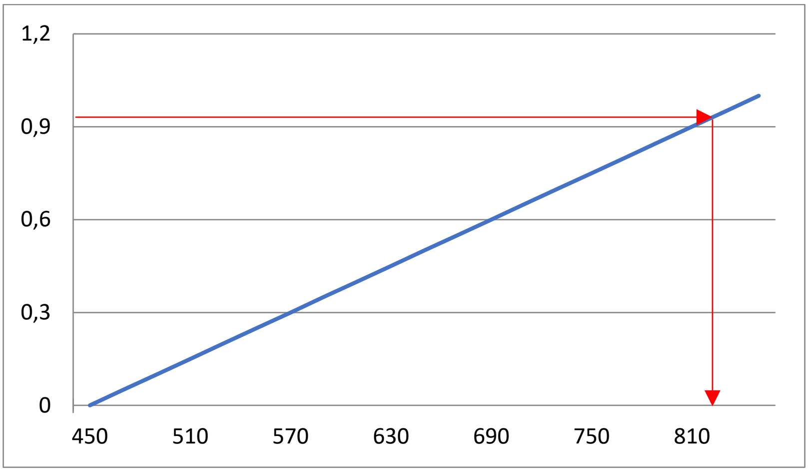

Figure 5.: Monte-Carlo simulation of continuous uniform distribution

The red arrows in Figure 5 show how random number generation in the interval [0, 1] produces a uniformly distributed random value, which in our study represents the parameter called the energy level. The value of the hardness depth was determined based on the relationship described in the previous chapter. The hardness depth values related to the induction tempering of the lifting cam (nose) using the Monte-Carlo method are described below. The results are presented in the bar chart shown in Figure 6, on which we can see the simulation of the evolution of the hardness depth in a series of observations consisting of 100 experiments.

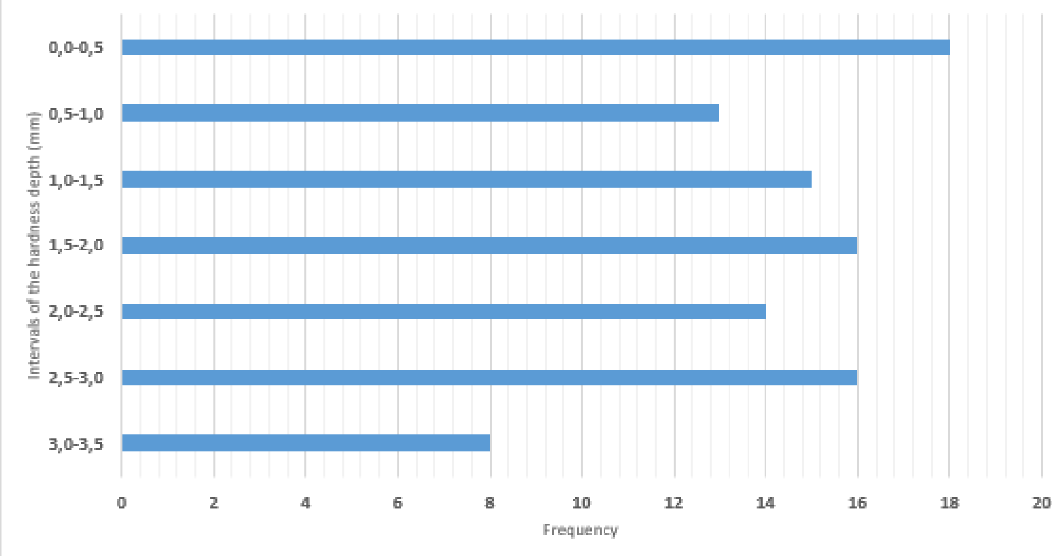

Figure 6.: Development of hardness depth intervals in the reflection of the frequencies of given hardness depths (mm) in the observation series consisting of 100 experiments

If cams with a hardness depth of 1.3 mm and 2.3 mm are considered adequate, taking into account the degree of material removal during further operations of the production process and - at the end of the process - also the customer's requirements. In this series of observations, it can be seen that only 34% of the products will be in the desired tolerance after induction training, which is illustrated in Figure 7.

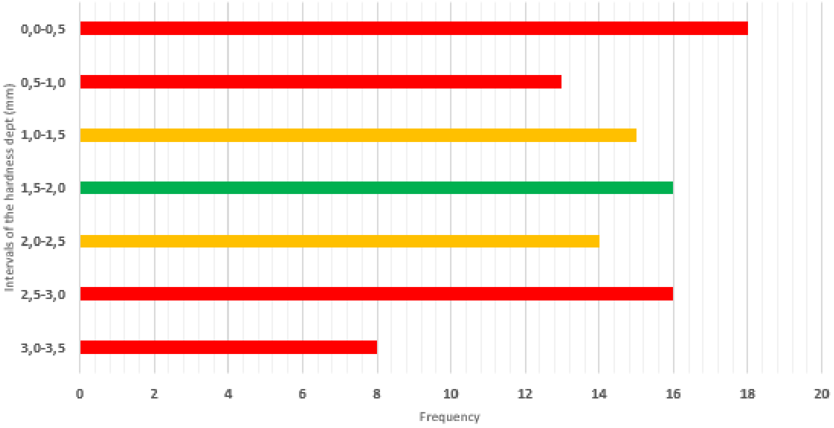

Figure 7.: Development of hardness depth intervals in the reflection of the frequencies of the given depths (mm) in the observation series consisting of 100 experiments, marked OK-NOK

It can be seen that with these settings, we could produce with 66% waste, which is unacceptable, as it is neither efficient nor economical. Thus, it is necessary to optimize the value of the energy level during the production process.

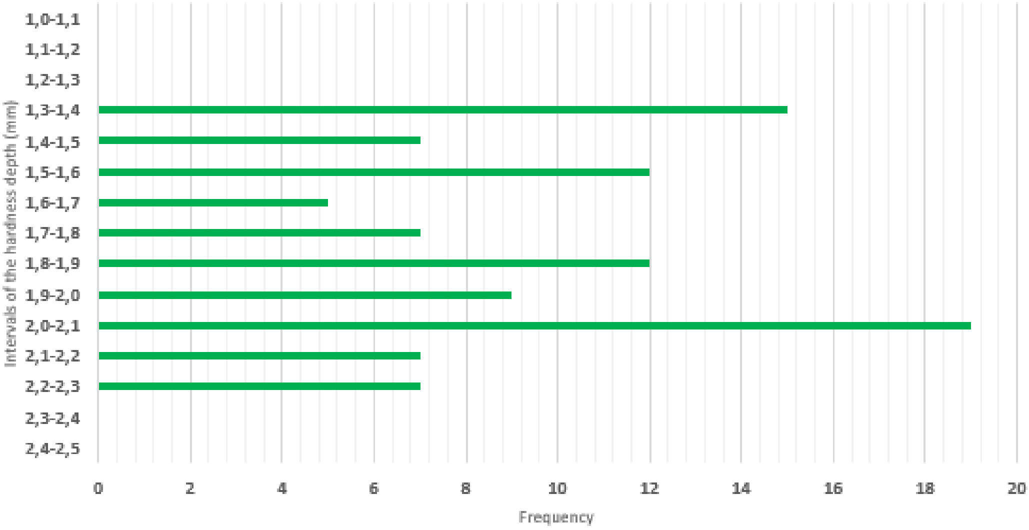

Figure 8.: Development of hardness depth intervals in the reflection of the frequencies of the given depths (mm) in the observation series consisting of 100 experiments, OK: 100%, NOK: 0%

Inserting the value of hardness depth (mm) into the related (hardness depth, nose) formula found in chapter of literature (lower limit: 1.3 mm and upper limit: 2.3 mm), we can also obtain the desired energy levels, in which case, if we repeat the Monte- Carlo simulation, we can see that in the observation series of 100 experiments, all (100%) hardness depth values will be within the desired tolerance. In the present case, these energy levels (lower and upper) are: 597 and 720, the results of which are illustrated in Figure 8.

SUMMARY, CONCLUSION

We can state that with the help of the Monte-Carlo method, knowing the data relationships, we can estimate the interval of the expected results, thus the ratio of the results, whether they fall into the desired interval or not, and with what efficiency. In addition, it can be a very useful method for the purpose, if the tolerance, i.e. lower and upper limit, of the process parameters of the given machine can be defined in order to achieve the goal, with the help of which the amount of waste or - even more decisive for the interested parties - waste costs can be minimized. In this way, the importance and meaning of the described method can be clearly demonstrated - in the knowledge of the mentioned antecedents. This is an opportunity, a method to reduce quality costs.

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