



DETERMINATION OF OPTIMAL CUTTING PARAMETERS

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Abstract

Determination of optimal machining parameters by using optimization techniques is continuous engineering task with the main aim to reduce the production cost and achieve desired product quality. Hence, this paper presents different optimization approaches to determine optimal values of cutting speed, feed and depth of cut with the purpose of improving the surface roughness obtained in turning operation. To achieve this, two experimental plans have been carried out based on the factorial design of experiments and the orthogonal arrays. By using these plans, the classical mathematical optimization was performed according to response model of the surface roughness as well as the Taguchi approach. The results of optimal turning parameters obtained with different optimization approaches were compared.

Key words: *Turning, Surface roughness, Optimization of parameters.*

1 INTRODUCTION

There are two main practical problems that engineers face in a manufacturing process. The first is to determine the values of the process parameters that will yield the desired product quality (meet technical specifications) and the second is to maximize manufacturing system performance using the available resources. The decisions made by manufacturing engineers are based not only on their experience and expertise but also on conventions regarding the phenomena that take place during processing. In the machining field, many of these phenomena are highly complex and interact with a large number of factors, thus preventing high process performance from being attained. To overcome these problems, the researchers propose models which try to simulate the conditions during machining and establish cause and effect relationships between various factors and desired product characteristics [1]. Surface roughness is a widely used index of product quality and in most cases a technical requirement for mechanical products. Achieving the desired surface quality is of great importance for the functional behaviour of a part. On the other hand, the process dependent nature of the surface roughness formation mechanism along with the numerous uncontrollable factors that influence pertinent phenomena, make almost impossible a straightforward solution. The most common strategy involves the selection of conservative process parameters, which neither guarantees the achievement of the desired surface finish nor attains high metal removal rates. Optimal surface roughness is necessary

because of improvement of corrosion resistance, tribology attributes and aesthetic appearance. Exceedingly low surface roughness requires additional expenses of production. Therefore selection of optimal cutting parameters is necessary in order to achieve optimal values of surface roughness [2]. The aim of this work is to present and discuss the different optimization approaches and strategies in order to improve surface roughness based on experimental research of longitudinal turning [3].

2 EXPERIMENTAL PROCEDURE AND RESULTS

In order to establish the correlation between cutting parameters and surface roughness in the mathematical model form, machining issues were incorporated with different cutting conditions, aiming at simulating them for surface roughness.

Experimental researches were performed on lathe machine "Georg Fisher NDM-16" at Production Engineering Institute University of Maribor. Materials used in the tests were carbon steel bars DIN Ck45 with 100 mm diameter and 380 mm length. Experiments were carried out by external machining turning tool with holder mark DDJNL 3225P15 and coated inserts type DNMG 150608-PM4025 under dry cutting conditions. The tool geometry was: rake angle 17° , clearance angle 5° , main cutting edge 93° with nose radius 0,8 mm. Before each cut, the insert was changed to eliminate the effect of tool wear. Surface roughness measurements were performed with SurfTest Mitutoyo SJ-201P with possibilities to measure surface roughness parameters (R_a , R_t , R_q , R_z). The paper presents optimization approaches relating to determine optimal values of cutting speed, feed and depth of cut with the purpose to improve surface roughness obtained by turning operation. To achieve this, it has been carried out experimental plans based on factorial design of experiment and orthogonal array it was performed classical mathematical optimization, according to response model of surface roughness, and the Taguchi approach (Table 1), respectively.

TABLE 1. $L_9 (3^4)$, with experimental results and calculated signal-to-noise (S/N) ratios [3]

Trial №	A	B	C	D	Experimental results, average R_a (μm)	S/N ratio
	cutting speed v_c	feed rate f	depth of cut a_p	experimental error		
1	1	1	1	1	0,77	2,306
2	1	2	2	2	1,33	-2,503
3	1	3	3	3	2,14	-6,595
4	2	1	2	3	1,11	-0,887
5	2	2	3	1	1,13	-1,037
6	2	3	1	2	2,01	-6,07
7	3	1	3	2	1,19	-1,487
8	3	2	1	3	1,05	-0,452
9	3	3	2	1	1,93	-5,715

The influence of the cutting parameters (v_c , f , a_p) on the arithmetic average roughness (R_a) values were presented in Table 1.

3 OPTIMIZATION METHODS

The optimisation of machining processes is essential for the achievement of high responsiveness of production, which provides a preliminary basis for survival in today's

dynamic market conditions. The ratio between costs and quality of products in each production stage has to be carefully monitored and immediate corrective actions have to be taken in the case of deviation from the desired trend [4]. To select the cutting parameters properly, there are numbers of optimization techniques and some of them were presented here [3, 5, 6, 7]. The optimum cutting parameters, in this case will be determined by the different optimization approaches, classical mathematical based on experimental obtained model, analytical based on literature known equation and Taguchi approach with the objective to improve surface roughness.

3.1 CONVENTIONAL APPROACHES

According to conventional approaches, two methods are described in this paper: classical mathematical analysis (CMA) and analytical study (AS). In the CMA the optimization of cutting process parameters were carried out by derivation of the obtained mathematical model based on experimental research. In this particular case derivation of predicted mathematical model will be performed with the aim to find optimal cutting parameters (v_c , f , a_p) in relation to surface roughness. On the other hand, AS is based on literature known analytical models [8]. To calculate the theoretical maximum peak-to-valley height (R_{tt}) and theoretical arithmetic average roughness (R_{at}), the following equations were used:

$$R_{tt} \approx \frac{f^2}{8r_\varepsilon} \times 1000, \quad R_{at} \approx \frac{0,032f^2}{r_\varepsilon} \times 1000 \quad (1)$$

where f is the feed rate (mm/rev) and r_ε is the tool nose radius (mm). Surface roughness model of finish turning based on the factorial design of experiment, as function of the cutting speed (v_c), feed rate (f) and depth of cut (a_p), has the following polynomial form:

$$R_a = 2,706 - 0,00614v_c - 16,98f - 1,5175a_p + 0,0132v_c f + 0,0054v_c a_p + 20,45fa_p - 0,048v_c fa_p + 0,0000056v_c^2 + 65,6f^2 - 0,325a_p^2. \quad (2)$$

In CMA the optimization of cutting process parameters was carried out by derivation of the obtained mathematical model (2).

3.2 TAGUCHI APPROACH

In this paper optimization based on Taguchi approach [3, 6, 9] is used to achieve more efficient cutting parameters and to compare results obtained with other optimization techniques presented in this paper. Parameter design is the key step in the Taguchi approach to achieve high quality without increasing cost. To solve this problem Taguchi approach uses a special design of orthogonal arrays where the experimental results are transformed into the S/N ratio as the measure of the quality characteristic deviating from the desired value. Table 1 shows that the experimental plan has three levels and an appropriate Taguchi orthogonal array with notation $L_9 (3^4)$ was chosen. The last column of parameters notation with D (Table 1) was used to estimate the experiment error. The right side of the table includes the average results (each trial has 3 samples) of the measured arithmetic average surface roughness (R_a) and the calculated signal-to-noise (S/N) ratio.

The S/N ratio, as the yardstick for analysis of experimental results, is calculated according to equation:

$$S/N = \eta = -10 \log_{10} \left(\frac{1}{n} \sum_{i=1}^n y_i^2 \right) \tag{3}$$

where is: η – signal-to-noise ratio (S/N); n – number of repetitions of the experiment; y_i – measured value of quality characteristic. The above equation, which is used to calculate the S/N ratio, is in relation to the *smaller-is-better* quality characteristics, what in the particular case means minimization of arithmetic average roughness to achieve the desired surface roughness.

3.3 NEURAL NETWORKS APPROACH

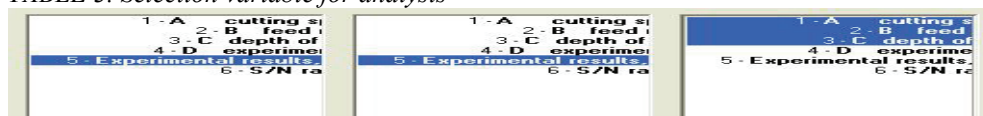
Over the past years, several technologies have been introduced to help engineers to analyze and design complex systems. One of these techniques is artificial neural network technology. An artificial neural network (ANN) is a young discipline of science, but is necessary to respect the intense of its development. The purpose of the ANN application is the imitation of a human thinking by solution of a specific problem. Another advantage for the ANN application is the ability of its adaptation to situation and environment changes. The possibility of incomplete data processing is anomalous [10]. The ANN technology has become very popular and is used in many fields. In the field of reliability assurance of machines and facilities can be applied in technical diagnostics, which deals with the application of diagnostic equipments during the normal function of objects (facilities). Some applications are possible by the implementation of hardware neural networks (neuroprocessors) in computer control of automatic diagnostic stations. In table 2 usher dates for neural network.

TABLE 2. Input and output data for ANN [11]

	1 A cutting speed v_c	2 B feed rate f	3 C depth of cut a_p	4 D experimental error	5 Experimental results, average R_a (μm)	6 S/N ratio
1	1	1	1	1	0,77	2,306
2	1	2	2	2	1,33	-2,503
3	1	3	3	3	2,14	-6,596
4	2	1	2	3	1,11	-0,887
5	2	2	3	1	1,13	-1,037
6	2	3	1	2	2,01	-6,07
7	3	1	3	2	1,19	-1,487
8	3	2	1	3	1,05	-0,452
9	3	3	2	1	1,93	-5,715

To select the variable for analysis was performance according to tables 3.

TABLE 3. Selection variable for analysis



On that Figure 1 is inscribed p-graph.

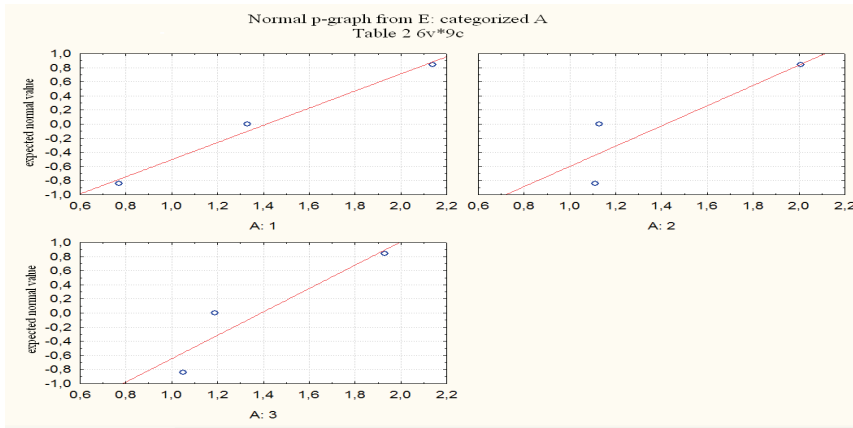


FIGURE 1. p-graph

On that Figure 2 is inscribed alignment for variables: A-cutting speed v_c , B-feed rate f , C-depth of cut a_p

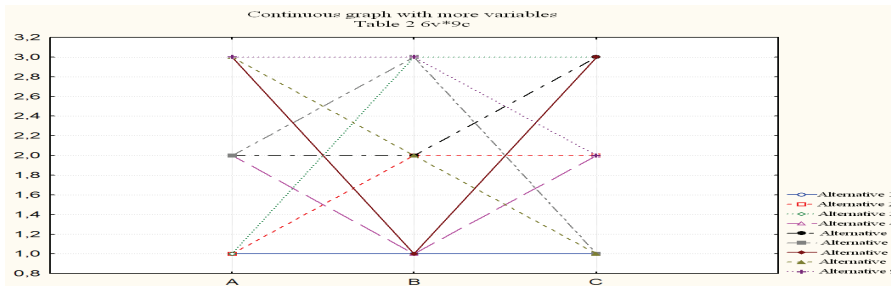


FIGURE 2. Alignment graph

4 DETERMINATION OF OPTIMAL CUTTING PARAMETERS

Optimal cutting parameters and their influences on the surface roughness were analysed. According to the analysis of variance the most influence on the surface roughness has the feed rate with 77,65% of contribution and there are no significant influences of the cutting speed and the depth of cut. The experimental verification test was compared with the results of optimal turning parameters obtained with different optimization approaches, Table 4. That obtained prediction model (2) is the very good base for finding the optimal parameters which was verified with the confirmation test and also with the contour graph, Figure 3.

TABLE 4. The comparison of the optimal results obtained with different methods and confirmation test

	Initial parameters	Optimal cutting parameters			Confirmation test
		Analytical model (1)	Prediction model (2)	Taguchi approach	
Level	A3B1C2	A1B1C1	A1B1C1	A1B1C1	A1B1C1
Surface roughness R_a (μm)	1,07	0,40	0,887	0,862	0,77

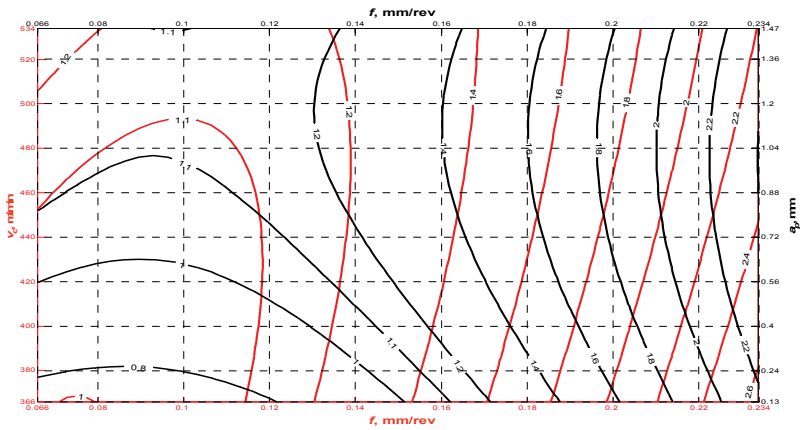


FIGURE 3. Surface roughness contour graph obtained by polynomial model (2)

The presented optimization techniques give accurate results (as indicated by the confirmation test) with small deviation between each other, except the analytical method.

5 CONCLUSIONS

In this paper an application of the different optimization approaches to find optimal cutting parameters is shown. The presented optimization techniques, classical and Taguchi, have its features, merits and limitations which is presented on the practical case. Hence, the following conclusions can be drawn: (i) Classical experimental design methods are too complex and not easy to use. A large number of experiments have to be carried out especially when the number of process parameters increases. To solve this problem, the Taguchi approach uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments. Also, the parameters value needs to be defined strictly numerical not as description of state. (ii) On the other hand, the advantage of classical experimental design methods is possibility to obtain mathematical model which is powerful tool to predict response for any of input parameters value within the experimental domain, and optimal values can be any of parameters point i.e. parameters are continuous and can take any real value. This is impossible in Taguchi approach, because optimal value have to be one of parameter levels. In addition, Taguchi approach is better for parameters with discrete values in contrast to classical optimization technique and continuous values. This all shows that the accuracy of network results depends on amount of training models. This case study expresses the way, how the neural networks can be designed and simulated. This proposed model does not include the testing with using of training models, but only training of given models of inputs and outputs. By the training set of input-output data we can determine the output value variation from desired value. In the case of different output parameters, we can modify the weights that the difference between actual and desired value is minimal. The advantage of STATISTICA CZ is the support of automated creation, training and testing of neural networks. In this contribution, a neural network application in operating determination of optimal cutting parameters to improve surface roughness based on different optimization approaches. Finally, all optimization techniques presented here have potentiality (more or less) to improve initial process parameters or in study case

the achievement of the desired surface roughness at longitudinal turning process, with high accuracy which was clearly verified by confirmation experiment.

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Acknowledgement

This article was created under the Grant VEGA No. 1/0511/08 – “Utilization of neuron network technology for reliability diagnosing of technical system of thermal energetic equipments” supported by Ministry of Education of Slovak Republic.