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Multi-Objective Optimization of Turning Parameters to Minimize Surface Roughness and Material Removal Rate Using TOPSIS Combining Entropy Weight

Nguyen Anh Thang[1], Truong Van Luong[2], Tran Van Hieu[3]

[1, 2, 3]Vietnam-Japan Center, Hanoi University of Industry

[1]Corresponding Author Email: *thangna[at]haui.edu.vn*

Abstract: ***Product surface quality, including surface roughness, is the most important parameter to be achieved in machining. However, due to competitive pressure in the current global economy, in addition to ensuring the technical requirements of products, improving cutting productivity is also a goal that must be achieved at the same time. This paper presents a multi-objective optimization model to optimize the technological parameters in the hard turning of 9XC steel. The two objectives are the surface roughness Ra and material removal rate MRR are optimized simultaneously. The investigated technological parameters are cutting speed Vc, feed rate fz and depth of cut ap. The TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) is applied to identify the optimal cutting parameters and the obtained results indicate that ap is the most significant factor followed by the fz and Vc..***

Keywords: TOPSIS, Turning, Multi-Objective Optimization, Surface Roughness, Material Removal Rate.

1. Introduction

In today's global competitive economy, the efficient use of resources of enterprises in production is an important factor to help businesses survive [1]. In machining in general and turning in particular, achieving surface roughness is the most important technical criterion. However, it is necessary to simultaneously ensure other objectives such as reducing energy consumption [2]; reduce processing costs [3]; increased cutting productivity; increase the life of cutting tools... In other words, the manufacturer must take measures to achieve many purposes simultaneously, and often these purposes are opposed to each other. For example, an increase in cutting productivity usually leads to a decrease in surface quality, i.e. an increase in surface roughness. Therefore, in order to achieve the optimal point, the harmony between these opposing purposes is a research direction that is being interested and widely applied. There are many multi-objective optimization methods that have been researched and published, such as TOPSIS [4], MOORA [5], DEAR [6]... In this study, the TOPSIS method was used to achieve the optimal score considering the two opposing purposes to be achieved, namely the minimum surface roughness Ra and the highest cutting productivity MRR.

2. Experimental Conduct

a) Workpiece

9XC round steel is a low-alloy tool steel. Due to the presence of Si and Cr elements, this 9XC steel has high hardenability and hardness. 9XC steel has good toughness, good tempering stability and small deformation during heat treatment. 9SiCr alloy tool steel can be used to manufacture tools with complex shapes, small deformation, high wear resistance and low speed cutting such as drill bits, thread tools, reamers, stamping dies, taps , threaded planks, threaded wheels…In Mechanical Engineering field, 9XC steel is used to manufacture machine parts, details subject to tensile loads such as screws, bolts, shafts, gears; machine parts through hot forging; moving parts or gears, piston shafts; wear-resistant details, high impact resistance, rolling shaft, ...In addition, in 9XC steel molds used to manufacture guide shafts, mold covers, bolts, screws, screws... The chemical composition of 9XC steel were shown in Table 1.

Table 1: Chemical Composition of 9XC Steel

	Chemical composition (%)						
9XC	C	Si	Mn	S	P	Cr	Cu
	0.85 ÷ 0.95	1.2 ÷1.6	0.3÷0.6	0.03	0.03	0.95÷1.25	0.03÷0.55

b) Experimental Machine

Figure 1: Experimental machine

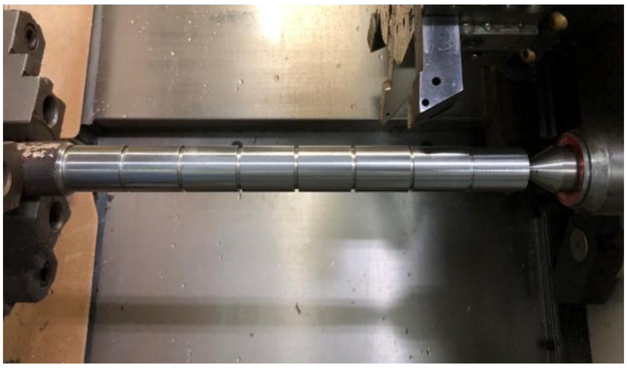

Figure 2: Experimental conduct

Table 2: Technical Parameters of experimental machine

Parameters	Value
Maximum of spindle speed	4000 rpm
Cross travel X-Axis	235 mm
Longitudinal Travel Z-Axis	520 mm
Number of spindles	2
Operation System	FANUC 10T
Length of Bed	mm
Width of Bed	mm
Maximum workpiece's weight	kg
Number of pockets	10
Length of machine	2345
With of machine	1680
Weight of machine	4200 kg
Maximum cutting tool diameter	25 mm

c) Experimental Design

RSM is a combination of statistical and mathematical techniques commonly used to analyze, model, and optimize processes. The purpose of this method is to establish an unknown relationship between the inputs and outputs of a process. Surface experiments are first deployed to fit linear or quadratic models [7]. The efficiency of RSM is significantly affected by the selection of suitable empirical matrix designs. In RSM, the Box-Behnken and CCD empirical matrices are most used. In this study research, the Box-Behnken matrix is applied, an RSM regression model was generated to represent the relationship between the depth of cut ap, cutting speed Vc, feed rate fz and surface roughness.

In the present study cutting speed, feed rate and depth of cut are taken as input cutting parameters. The ranges of these parameters were decided based on the machine tool capacity and manufacturer recommendations and are tabulated in table 1.

Table 3: Considered variants and their corresponding values

Variants	Level		
	-1	0	1
Cutting speed (Vc) (meter/minute)	140	220	300
Feed rate (fz) (mm/round)	0.04	0.11	0.18
Depth of cut (ap) (mm)	0.3	0.65	1.0

TOPSIS was presented by Hwang and Yoon first in 1981 to determine the best options based on the concept of compromise alternatives. A compromise can be considered to select the best solution with the shortest Euclidean distance from the ideal solution and the furthest Euclidean distance from the negative solution [8]. In the TOPSIS method, the weight set is not considered to calculate, is selected by the user. In this work, the entropy weight is used combined with the TOPSIS method because of the high accuracy. [9]–[11]

The Entropy-based TOPSIS is performed by the following steps [8]:

Step 1: Arranging the alternatives in the order of matrix (1).

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1j} & x_{1n} \\ x_{21} & \cdots & x_{2j} & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{i1} & \cdots & x_{ij} & x_{in} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & \cdots & x_{mj} & x_{mn} \end{bmatrix} \qquad (1)$$

Where:
xij, is the value of the criterion j in the alternative i;
n is the number of criteria
m is the number of alternatives

Step 2: Determination of the normalized ratings by (2).

$$x'_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}} \qquad (2)$$

Step 3: Assigning the weight set for the criteria

Step 4: Calculating the weighted normalized decision matrix, where wj is the weight of the criterion j, is calculated by equation (3).

$$Y = w_j . x'_{ij} \qquad (3)$$

Step 5: Determining the best and the worst solutions using formula (4), (5) below:

$$A^+ = \{y_1^+, y_2^+, \dots, y_j^+, \dots, y_n^+\} \qquad (4)$$

$$A^- = \{y_1^-, y_2^-, \dots, y_j^-, \dots, y_n^-\} \qquad (5)$$

Where: y_j^+ and y_j^- is the best and the worst solution of the j criterion, respectively.

Step 6: Calculating S_i^+ và S_i^- by formula (6), (7) below:

$$S_i^+ = \sqrt{\sum_{j=1}^{n} \left(y_{ij} - y_j^+\right)^2} \qquad i = 1, 2, \dots, m \qquad (6)$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} \left(y_{ij} - y_j^-\right)^2} \qquad i = 1, 2, \dots, m \qquad (7)$$

Step 7: Determining the candidate evaluation criteria C_i^* by equation (8)

$$C_i^* = \frac{S_i^-}{S_i^+ + S_i^-} \quad i = 1, 2, \dots, m; \quad 0 \le C_i^* \le 1 \qquad (8)$$

Step 8: Arranging the ranking according to the rules: largest of C_i^* is the best alternative.

Calculating the weight set using EWM (Entropy Weight Method):

Step 1: Transform the responses data to non-dimension form using formula (9)

$$w_j = \frac{1 - e_j}{\sum_{j=1}^{n}(1 - e_j)} \quad (9)$$

Step 2: Determining entropy eij by formula (10)

$$e_{ij} = -\sum_{i=1}^{m}[p_{ij}\ln(p_{ij})] - (1 - \sum_{i=1}^{m} p_{ij}) x \ln(1 - \sum_{i=1}^{m} p_{ij}) \quad (10)$$

Table 4: Entropy values set

e1j	e2j
1.2613	8.0344

Step 3: Determining weight set using EWM (Entropy Weight Method):

Table 5: Entropy weights set

w1j	w2j
0.0358	0.9642

3. Results and Discussion

Monitoring systems can anticipate failures and allow turbine owners to schedule for repairs in addition to the regular maintenance of the turbines. In addition to monitoring the turbine parameters it is possible to control the wind turbines as stating, stopping and reset can be performed from the control room in the site and also remotely in case of need. Fig. 6 shows a block diagram for monitoring system of wind turbines and samples of the results are shown in fig.7.

Table 6: The experimental results

Alt.	Vc	ap	f	Ra	MRR	r1	r2
A1	140	0.65	0.18	2.23	756.0	0.468	0.236
A2	220	0.65	0.11	1.42	726.0	0.297	0.226
A3	300	0.65	0.04	0.95	360.0	0.199	0.112
A4	140	0.3	0.11	1.26	462.0	0.264	0.144
A5	220	0.3	0.18	1.51	1188.0	0.316	0.370
A6	220	0.65	0.11	0.94	726.0	0.198	0.226
A7	140	1	0.11	0.82	462.0	0.172	0.144
A8	300	0.3	0.11	0.68	990.0	0.142	0.309
A9	140	0.65	0.04	0.91	168.0	0.191	0.052
A10	220	0.65	0.11	1.23	726.0	0.257	0.226
A11	220	0.3	0.04	0.77	264.0	0.162	0.082
A12	220	1	0.18	1.63	1188.0	0.341	0.370
A13	300	0.65	0.18	1.61	1620.0	0.338	0.505
A14	300	1	0.11	0.83	990.0	0.175	0.309
A15	220	1	0.04	0.35	264.0	0.073	0.082

The results of ranking to alternatives are presented in Table 7

Table 7: The matrix of alternatives

Alt	v1	v2	S+	S-	C*	Rank
A1	0.2809	0.0943	0.1078	0.2484	0.6974	2
A2	0.1780	0.0906	0.1517	0.1514	0.4995	5
A3	0.1193	0.0449	0.2254	0.0794	0.2606	11
A4	0.1582	0.0576	0.1895	0.1203	0.3883	7
A5	0.1898	0.1482	0.1059	0.1938	0.6467	4
A6	0.1185	0.0906	0.1970	0.1023	0.3417	10
A7	0.1031	0.0576	0.2290	0.0699	0.2339	12
A8	0.0850	0.1235	0.2111	0.1106	0.3437	9
A9	0.1146	0.0210	0.2459	0.0710	0.2240	13
A10	0.1543	0.0906	0.1687	0.1307	0.4366	6
A11	0.0973	0.0329	0.2497	0.0550	0.1805	14
A12	0.2046	0.1482	0.0934	0.2052	0.6872	3
A13	0.2026	0.2021	0.0783	0.2410	0.7549	1
A14	0.1048	0.1235	0.1928	0.1194	0.3824	8
A15	0.0436	0.0329	0.2914	0.0120	0.0395	15

4. Conclusion

From this study, the following conclusions can be drawn:

Entropy-based TOPSIS method can be used to perform the multiple objective optimizations problems.

In finish turning 9XC Carbon steel, the cutting parameters (cutting speed Vc=300 m/min; feed rate fz=0.18mm/round; and depth of cut ap = 0.65 mm) will be given the best solutions, when considering in both of surface roughness and material removal reate at the same time.

In milling S50C carbon steel under MQL, the influence of flow rate is insignificant. So, this factor could be considered to ignore in the subsequent studies.

References

[1] J. P. Davim and V. P. Astakhov, *Machining of Hard Metals*. 2011.

[2] C. Liu, C. Ren, G. Wang, Y. Yang, and L. Zhang, "Study on surface defects in milling Inconel 718 super alloy," *J. Mech. Sci. Technol.*, vol. 29, no. 4, pp. 1723–1730, 2015, doi: 10.1007/s12206-015-0345-1.

[3] Harvey Performance Company, J.-S. B. Chen, Y.-K. Huang, and M.-S. Chen, "HEM Guidebook," *Int. J. Mach. Tools Manuf.*, vol. 45, no. 9, pp. 1070–1076, 2017, [Online]. Available: https://www.harveyperformance.com/

[4] T. D. H. Van Canh Nguyen, Thuy Duong Nguyen, "Cutting Parameter Optimization in Finishing Milling of Ti-6Al-4V Titanium Alloy under MQL Condition using TOPSIS and ANOVA Analysis," *Eng. Technol. & Appl. Sci. Res.*, vol. 11, no. 1, pp. 6775–6780, 2021, doi: https://doi.org/10.48084/etasr.4015.

[5] R. V. R. PhD and R. V. Rao, *Decision Making in the Manufacturing Environment: Using Graph Theory and Fuzzy Multiple Attribute Decision Making Methods*. Springer-Verlag London, 2007.

[6] M. M. A. Khan, M. A. H. Mithu, and N. R. Dhar, "Effects of minimum quantity lubrication on turning AISI 9310 alloy steel using vegetable oil-based cutting fluid," *J. Mater. Process. Technol.*, vol. 209, no. 15–16, pp. 5573–5583, 2009, doi:

10.1016/j.jmatprotec.2009.05.014.

[7] Box, G.E.P.Draper, and N.R., "Empirical Model Building and Response Surfaces," *John Wiley Sons*, 1987.

[8] J. Huang, "Combining Entropy Weight and TOPSIS Method for Information System Selection," in *CIS 2008*, 2008, pp. 1281–1284. doi: 10.1109/ICCIS.2008.4670971.

[9] J. K. Alireza Alinezhad, *New Methods and Applications in Multiple Attribute Decision Making (MADM)*. Springer International Publishing, 2019.

[10] J.-J. H. Gwo-Hshiung Tzeng, *Multiple Attribute Decision Making: Methods and Applications*. CRC, 2011.

[11] T. Temuçin, H. Tozan, Ö. Vayvay, M. Harničárová, and J. Valíček, "A fuzzy based decision model for nontraditional machining process selection," *Int. J. Adv. Manuf. Technol.*, vol. 70, no. 9, pp. 2275–2282, 2014, doi: 10.1007/s00170-013-5474-z.