PARAMETER-BASED OPTIMIZATION OF THE DRY MILLING PROCESS FOR ENERGY SAVING

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Abstract: *This paper addressed a multi-response optimization to enhance the power factor (PF) and decrease the energy consumption (EC) for the dry machining AISI H13 steel. The cutting speed (V), depth of cut (a), feed rate (f), and nose radius (r) were the processing inputs. The relationships between inputs and outputs were established using the response surface models (RSM). The desirability approach (DA) was used to observe the optimal values. The results showed that the technical outputs are primarily influenced by the f and V. The reduction of EC is approximately 33.84%, while the PF improves around 33.12%, respectively, as compared to the initial parameter setting.*

Keywords: Dry milling, Power factor, Energy consumed, RSM, DA

1. INTRODUCTION

The dry machining (DM) is an effective solution to decrease the manufacturing costs, protect the worker health, and resolve the environmental issue. The total cost of the lubrication, including the manufacturing, usage, and recycling account to about 7-17% of cutting tool cost and it is greater than overhead and labor costs (Gupta et al., 2016). Fortunately, the dry machining is an eco-friendly approach to replace the conventional one due to the elimination of the lubrication, leading a decrease in air and water pollution.

The improvements in the technical parameters of dry machining processes have been considered by many researchers. Traditionally, the technological outputs, such as surface integrity, cutting temperature, and tool life were optimized by means of optimal machining factors (Yang et al., 2009; Sun et al., 2015). The tool wear and hole quality for the helical milling were analyzed (Le et al., 2014). The temperature variations in the workpiece and cutting tool were explored for the DM Inconel 718 (Coz et al., 2014). The surface integrity was improved for milling processes of the Al-Zn-Mg-Cu alloy (Jomaa et al., 2017), aluminum (Khettabi et al., 2017), and

Ti-6Al-4V alloy (Safari et al., 2015) and the hard turning of AISI 52100 (Shihab et al., 2014). The grey relational analysis was applied to achieve optimum inputs for the surface properties, energy criteria, and production rate (Angappan et al., 2014). As a result, a few studies have focused on the parameter optimization for improving the technological performances of the dry machining processes. The optimization of the process parameters and cutting tool's parameters for simultaneous improvement of the *PF* and *EC* has not been considered in the aforementioned works.

To remove the research gap, a multiple-response optimization of machining parameters of the dry milling process of AISI H13 steel has considered in this paper for improving the *PF* and *EC*. The AISI H13 steel is chosen as the workpiece due to its wide application in the molding, automotive, and marine industry.

2. OPTIMIZATION ISSUE

The power factor (*PF*) is defined as the ratio of the active power consumption (*APC*) to the apparent power (*APP*):

$$PF = \frac{APC}{APP} = \frac{APC}{\sqrt{APC^2 + RP^2}} \qquad (1)$$

In this paper, energy consumption in cutting time (*EC*) is calculated using Eq. 2:

$$EC = PC \times t_c \qquad (2)$$

where t_c denotes the cutting time.

3. EXPERIMENTS AND MEASUREMENTS

Milling tests are performed in a Spinner U620 machining center (Fig. 1) arcording to the Box-Behnken matrix (Bagaber et al., 2018). The AISI H13 steel is chosen as the workpiece due to its wide applications in molding, automotive, aerospace, and marine industry. The dimensions of machining specimens are 350 mm×150 mm×25 mm. The tool holder equipped with two inserts was 12 mm in diameters. Power Meter KEW6305 is used to measure the power consumption in the milling process. The representative values of the power consumed at different inputs are depicted in Fig. 2. The experimental results of the dry milling process are given in Table 1. The parameter levels are selected based on the recommendation of the manufacturer of the cutting tool and the machine tool characteristic. The experimental run at the highest level of the factor were conducted to ensure the machining power.

4. RESULTS AND DISCUSSIONS

4.1. Parameter influences

The RSM models showing the relationships between the inputs and outputs are expressed as:

$$PF = 0.52958 - 0.00121V + 0.03985a + 0.42442f - 0.45639r \quad (3)$$
$$+ 0.000104Va - 0.00579Vf + 0.00114Vr + 0.5848af + 0.01214ar$$
$$+ 0.69679fr + 0.000011V^2 + 0.07923a^2 + 11.96583f^2 + 0.4431r^2$$

$$EC = 183.15010 - 1.26758V + 29.73569a - 1571.26898f \quad (4)$$
$$+ 11.58556r - 0.094052Va + 3.26975Vf - 0.02723Vr$$
$$- 136.90884af - 2.32824ar - 137.55344fr + 0.00338V^2$$
$$+ 2.51247a^2 + 5766.25935f^2 + 11.50144r^2$$

The R^2-values of the PF and EC are 0.9983 and 0.9921, respectively, indicating the good agreements between experimental and predictive values. The adjusted R^2-values of the PF and EC are 0.9959 and 0.9810, respectively, proving the satisfactoriness of the models proposed. Additionally, the predicted R^2-values of the PF and EC are 0.9495 and 0.9449, respectively, indicating the significances of the RSM models in any new data. Therefore, the adequacy of the RSM models proposed for the responses is acceptable (Fig. 3).

The effects of the inputs on the PF are shown in Fig. 4. It was pointed out that an increased factor, such as the cutting speed, depth of cut, feed rate, and nose radius leads to a higher power factor. At a higher value of the parameters, the increased load on the motor is consumed to remove a higher material removal volume. Therefore, the active power increases and reactive power decreases, resulting in an increment in the power factor.

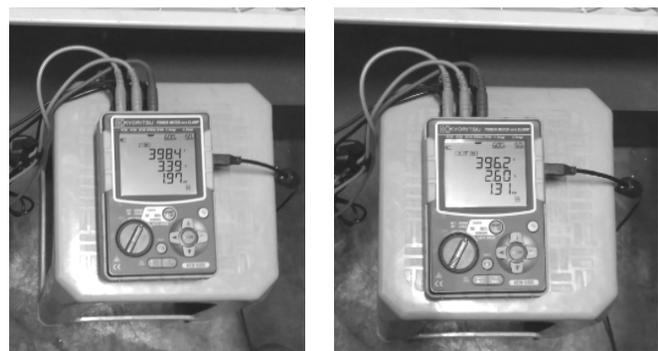*Figure 1. Experiments and measurements*

Figure 2. Power consumption

Table 1. Experimental results

No.	V (m/min)	a (mm)	f (mm/z)	r (mm)	PF	EC (kJ)
1	110	0.20	0.04	0.4	0.518	50.33
2	110	0.60	0.12	0.8	0.867	25.46
3	110	0.60	0.08	0.4	0.652	31.56
4	60	0.60	0.08	0.2	0.611	53.66
5	160	0.60	0.12	0.4	0.851	18.42
6	60	0.60	0.12	0.4	0.736	42.60
7	110	0.20	0.12	0.4	0.690	21.99
8	60	0.60	0.08	0.8	0.685	59.13
9	60	1.00	0.08	0.4	0.703	61.68
10	110	1.00	0.12	0.4	0.868	26.72
11	110	1.00	0.08	0.2	0.732	35.41
12	160	0.60	0.08	0.2	0.719	22.84
13	160	1.00	0.08	0.4	0.835	27.26
14	60	0.20	0.08	0.4	0.547	48.96
15	160	0.60	0.04	0.4	0.690	44.62
16	110	0.60	0.04	0.2	0.566	54.03
17	60	0.60	0.04	0.5	0.529	94.95
18	110	1.00	0.04	0.4	0.659	63.82
19	160	0.20	0.08	0.4	0.671	22.07
20	110	0.60	0.12	0.2	0.752	23.74
21	110	0.60	0.04	0.8	0.648	62.35
22	160	0.60	0.08	0.8	0.862	26.68
23	110	0.20	0.08	0.2	0.576	28.23
24	110	0.20	0.08	0.8	0.681	32.95
25	110	1.00	0.08	0.8	0.843	39.02

The interaction impacts of the processing conditions on energy consumption are shown in Fig. 5. A higher value of the feed or speed leads to a decrease in the cutting time, resulting in a reduction in the energy consumed. An increment in the depth of cut causes larger plastic deformation, leading to greater resistance in the chip formation; hence, higher energy is consumed. An increased radius leads to an increment in cutting edge; hence, more energy is required to overcome the resistance friction.
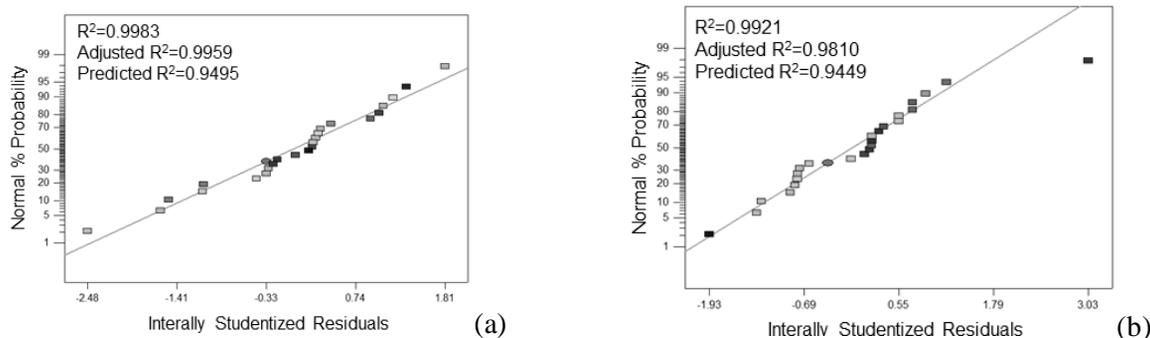

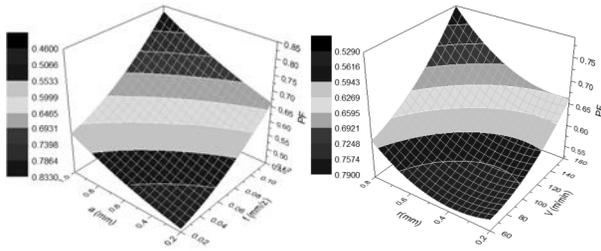*Figure 3. Investigation of adequacy of RSM models*

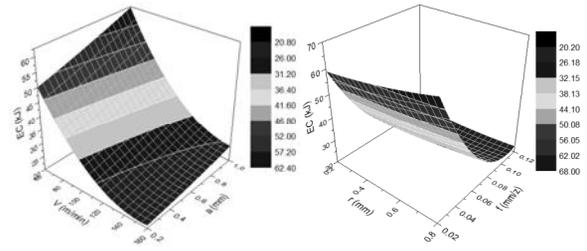*Figure 4. The effects of machining parameters on the PF*

Figure 5. The effects of machining parameters on the EC

4.2. Optimization results

The developed equations showing the relationship between process parameters and machining responses are used to find optimal parameters with the aids of the DA (Zhang et al., 2017). The ramp and desirability graphs are shown in Fig. 6. The optimal values of the inputs and outputs are listed in Table 2. The reduction of the *EC* is about 33.84% while the *PF* increases around 33.12%, respectively, as compared to the initial values.
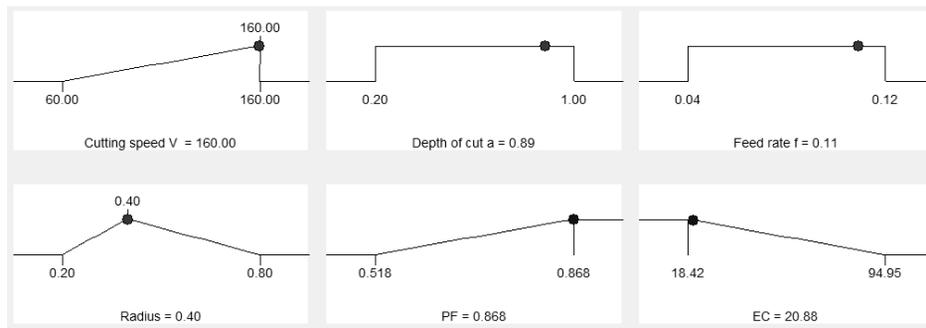

Figure 6. Optimization results with

Table 2. Optimization results

Method	Optimization parameters				Responses	
	V (m/min)	*a* (mm)	*f* (mm/z)	*r* (mm)	*PF*	*EC* (kJ)
Initial	110	0.60	0.08	0.4	0.652	31.56
DA	160	0.88	0.11	0.4	0.868	20.88
Improvement (%)					33.12	-33.84

5. CONCLUSION

This paper presented a machining parameter-based optimization for the dry machining AISI H13 steel in order to maximize the *PF* and decrease the *EC*. The RSM models for the *PF* and the *EC* having R^2-values of 0.9983 and 0.9921, respectively indicate a good correlation between the predicted and experimental values. The predictive models developed can be used for the dry machining AISI H13 steel to forecast the optimal parameters with sufficient accuracy. The maximal levels of the inputs are recommended to increase the *PF*. The highest values of the speed and feed can be used to save the *EC*, while the lowest levels of the *a* and *r* cause a decrease in energy consumed. The optimal values of the *V*, *a*, *f*, and *r* are 160 m/min, 0.88 mm, 0.11 mm/z, and 0.4 mm, respectively. The *PF* improves about 33.12% while the *EC* decreases approximately 33.84% at the optimal solution.

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Tóm tắt:
TỐI ƯU HÓA CÁC THÔNG SỐ CÔNG NGHỆ CHO QUÁ TRÌNH PHAY KHÔ ĐỂ TIẾT KIỆM NĂNG LƯỢNG

Nghiên cứu này đề cập đến bài toán tối ưu hóa đa mục tiêu để nâng cao hệ số công suất (PF) và giảm mức năng lượng tiêu thụ (EC) cho quá trình phay khô thép AISI H13. Tốc độ cắt (V), chiều sâu cắt (a), lượng tiến dao (f), và bán kính mũi dao (r) là các thông số công nghệ. Hàm mục tiêu được thiết lập thông qua phương pháp bề mặt đáp ứng (RSM). Phương pháp hàm mong đợi (DA) được sử dụng để dự báo các giá trị tối ưu. Kết quả cho thấy các hàm mục tiêu chịu ảnh hưởng chủ yếu bởi f và V. Năng lượng tiêu thụ có thể giảm xấp xỉ 33,84% trong khi hệ số công suất được nâng cao khoảng 33,12%
Từ khóa: Phay khô, hệ số công suất, năng lượng, bề mặt đáp ứng, Hàm mong đợi.