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Optimization of Process Parameters for Cutting Force for Aluminium 7010 in CNC End Milling Process

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ABSTRACT:

In this paper CNC end milling process have been optimized in cutting force and surface roughness based on the three process parameters (i.e.) speed, feed rate and depth of cut. Since the end milling process is used for abrading the wear caused is very high, in order to reduce the wear caused by high cutting force and to decrease the surface roughness, the optimization is much needed for this process. Especially for materials like aluminium 7010, this kind of study is important for further improvement in machining process and also it will improve the stability of the machine.

KEYWORDS:

End milling process; Cutting force; Surface roughness; RSM

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1. Introduction

End milling process is used largely in Aerospace industry due to its versatility and efficiency. End milling process is mostly used in precision-based industries. So it is required to improve the output parameter such as surface roughness, cutting force, tool wear etc. we can improve the output parameters by choosing correct optimum relation of the output parameters (cutting force, surface roughness) with the process parameters such as speed, and feed rate, depth of cut. It will also help us to improve the economic use of the machine since its stability can be improved. The cutting force will have an adverse effect on the machining surface roughness, machining cost, tool wear rate etc [1-3]. These approaches may be suitable for some range. Researchers have been done by experimental approaches to study the relationship between cutting forces and independent cutting parameter combination [4-6]. The experimental approach has helped us investigated the effect of cutting parameters on cutting forces by varying the combination of the three level of the parameter [7].

This study considers the effect of simultaneous variations of three cutting parameters (cutting speed, feed rate, axial depth of cut) on the behaviour of cutting forces (cross feed, in feed and thrust). The response surface methodology (RSM) is used to obtain the relationship between process parameters and output variables. RSM is a mathematical and statistical technique used for obtaining the relationship between the input parameters (process parameter) and the output variables (cutting force and surface roughness). RSM saves cost and time on conducting metal cutting experiments by reducing the overall number of required tests. In addition, RSM helps describe and identify, with a great accuracy, the effect of the interactions of different independent variables on the response when they are varied simultaneously. RSM has been extensively used in the prediction of responses such as tool life, surface roughness, and cutting forces [8]. Feed rate is the main factor, and side cutting edge angle as a secondary factor affected the tangential force which is affected by speed [9-10]. In this study, the cutting force produced when end-milling of AL7010 is investigated using response surface method.

2. Tool and work piece selection

H490 ANKX 090408PNTR - double sided rectangular inserts with 4 helical cutting edges are used for heavy application. A carbide insert tool is used in this experiment. A tough submicron substrate that is improved with Ti AI N PVD coated grade for better chip flow is used. The tool specifications are as follows:

- H490 - HELIDO 490
- A-850 (parallelogram)
- N-00(relief angle)
- K-0.013mm corner height, 0.025mm thickness, 0.05-0.13mm inscribed circle, diameter - 20mm
- X-double sided rectangular helical cutting edge
- 09 - edge length
- 04-4.76 - thickness
- 08 - 0.8 corner radius

- P-00 (wiper lead angle)
- N - 00 (wiper clearance angle)
- T-T - land (cutting edge preparation)
- R - Right hand cutting only

The work material used in the experiment is aluminium 1070 alloy. Aluminium is a wrought alloy having good corrosion resistance. The chemical composition of this alloy is Al ≥ 99.97, Fe ≤ 0.25, Si ≤ 0.20, Zn ≤ 0.040, Cu ≤ 0.049, others (each) ≤ 0.030. The density of aluminium 1070 is 2.70gm/cm^3 and the tensile strength of 95Mpa.

2.1. Method for cutting force analysis

The cutting force has three components cross feed, in feed, thrust force. But in the case of milling operation, the main influential component is cross feed. The cross feed is influenced by the speed. The feed and thrust forces are influenced by feed rate and depth of cut. The most dominant force in the end milling process is the tangential force. The tangential force is related to the speed of the process. The process speed influences the cross feed that is already known. Then in the case of cutting force measurement, the major force component that wants to be measured is cross feed.

3. Experimental setup and procedure

Before conducting the experiments the level of process parameters is chosen. The process parameters used in the experiments is cutting speed, feed rate, depth of cut. The milling is done using a vertical milling machine and milling dynamometer is fixed to the machine [11, 12]. The machine setup with the work piece and dynamometer is shown in Fig. 1. The milling dynamometer is used to measure the force during the experimentation and shown in Fig. 2. The aluminium block is fixed in the vertical machining centre [14]. The dimension of work is 107×100mm; diameter of the end mill cutter is 20mm. The cutting parameters along with various levels are shown in Table 1. Using MINITAB 17, the number of experiments in order and its subsequent array is determined. It generates totally 20 experiments. They are conducted in 4 sets, each set has 5 experiments. At the end of the each set, work piece was face milled.

Fig. 1: Vertical machining centre

Fig. 2: Milling tool dynamometer

Table 1: Level of process parameters

Factors	-1	0	1
Speed(rpm)	800	1000	1200
Feed rate(mm/min)	200	300	400
Depth of cut(mm)	0.2	0.4	0.6

4. Results and discussion

4.1. First order linear equation

After conducting the experiments, as of 20 experiments, the value of experiments is taken and the first order linear equation is formulated using MINITAB17. The first order linear equation for to determine the cutting force is arrived using below Eqn. (1),

$$\text{Cutting force} = 24.8 - 0.0365X_1 + 0.0660X_2 + 51.0X_3$$

Where X_1 = speed, X_2 = feed rate and X_3 = depth of cut. The ANOVA data is presented in Table 1. The surface plot and contour plot of cutting force in linear form for different combinations are presented in Figs. 3 to 5. A comparison of theoretical prediction and experimental result values of cutting force are given in Table 2. The values in Tables 1 and 2 are only valid for Aluminium 7010 alloy and tungsten carbide tool. The experimental value is nearly close to the theoretical predicted value. The confidence level used in this calculation is 95%. The ANOVA for first order equation shows that depth of cut is the significant parameter that mainly influences the cutting force [15-17]. From the Eqn. (1), we can easily note that coefficient of depth of cut and feed rate is positive so it means that it is proportional to cutting force. Cutting force increases with an increase in cutting speed. The response of cutting force is significantly influenced by the depth of cut and followed by the feed rate and least significant by the speed. By this analysis cutting force is decreased by increasing the speed, by decreasing the feed rate and the depth of cut [18-20].

Table 1: Analysis of variance: 1st order equation

Source	DF	Sec SS	Adj SS	Adj MS	F-value	P-value
Blocks	2	24.38	24.38	12.19	0.15	0.865
Regression	3	2008.9	2008.90	669.63	8.06	0.002
Linear	3	2008.9	2008.90	669.63	8.06	0.002
Speed (rpm)	1	532.9	532.90	532.90	6.41	0.024
Fd. rate (mm/min)	1	435.6	435.60	435.60	5.24	0.038
Cut depth (mm)	1	1040.4	1040.4	1040.4	12.52	0.003
Residual error	14	1163.27	1163.27	83.09		
Lack-of-fit	11	1163.27	1163.27	105.75	*	*
Pure error	3	0.00	0.00	0.00		
Total	19	3196.55				

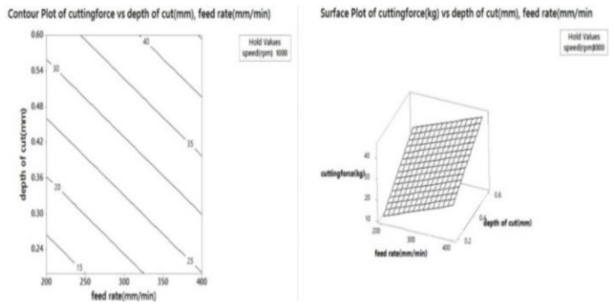

Fig. 3: Cutting force for feed rate vs. Depth of cut

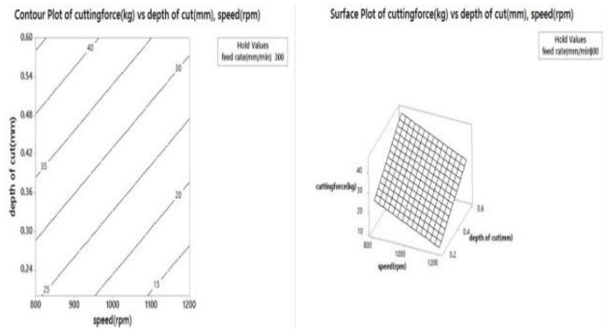

Fig. 4: Cutting force depth of cut vs. Speed

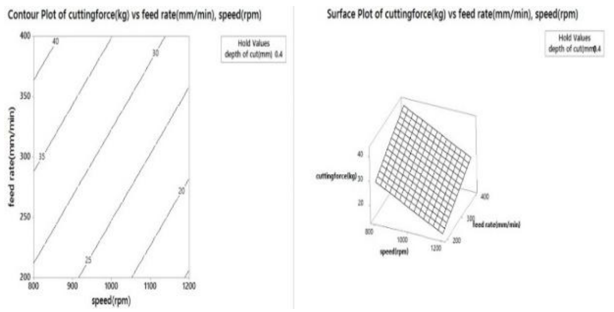

Fig. 5: Cutting force for feed rate vs. Speed

Table 2: Theoretical vs. Experimental results: 1st order equation

Speed (rpm)	Feed rate (mm/min)	Depth of cut (mm)	Cutting force(kg) Theoretical	Cutting force(kg) Experimental
800	300	0.4	35.8	35
1000	300	0.4	28.5	22
1000	300	0.2	18.3	37
1200	300	0.4	21.2	29
1000	400	0.4	35.1	33
1000	300	0.6	38.7	36
1000	300	0.4	28.5	22
1000	200	0.4	21.9	26
1200	400	0.2	17.6	18
1200	200	0.6	24.8	17
1000	300	0.4	28.5	22
1000	300	0.4	28.5	22
800	200	0.2	19	19
800	400	0.6	52.6	68
1200	200	0.2	4.4	11
1000	300	0.4	28.5	22
800	400	0.2	32.2	23
800	200	0.6	39.4	46
1200	400	0.6	38	43
1000	300	0.4	28.5	22

4.2. Second order quadratic equation

The second order Dox-Betnken design model is used to find the cutting parameters and its interactions that influences the cutting force in that above experiment. The cutting force is arrived using below Eqn. (2),

$$\text{Cutting force} = 106-0.132X_1 - 0.080X_2 - 34X_3 + 0.000067X_1^2 + 0.000017X_2^2 + 179X_3^2 + 0.000044X_1 * X_2 -0.1281X_1 * X_3 + 0.231X_2 * X_3$$

Where X_1 = speed, X_2 = feed rate and X_3 = depth of cut. The surface plot and contour plot of cutting force in linear form for different combinations are presented in Figs. 6 to 8. The ANOVA data is presented in Table 3. A comparison of theoretical prediction and experimental result values of cutting force are given in Table 4. From the ANOVA table confidence level used in the analysis is 95%. The calculated F-value of depth of cut is greater than F-critical. It indicated that the depth of cut is significant factor with the significance level of 0.05. The values of cutting force during the experiment with combination of high feed rate and depth of cut along with low cutting speed gives higher increase in the cutting force. All experimental value is nearly close to the predicted theoretical value. In the results of first order equation, the depth of cut is the most significant parameters that influence the cutting force but in the second order equation and table values the interaction of depth of cut and feed rate increases drastically increase the cutting force.

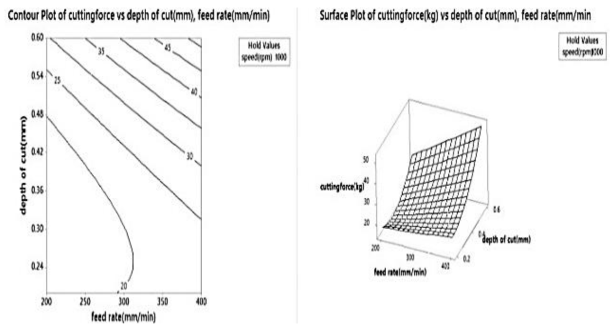

Fig. 6: Cutting force for depth of cut vs. Feed rate

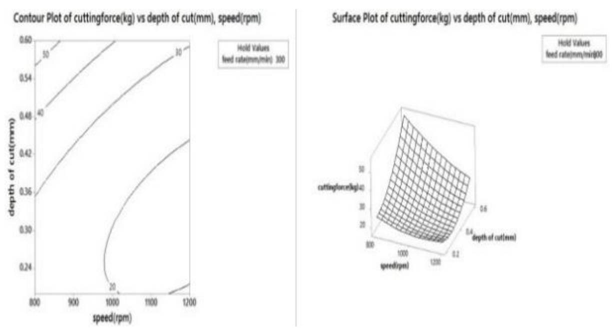

Fig. 7: Cutting force for depth of cut vs. Speed

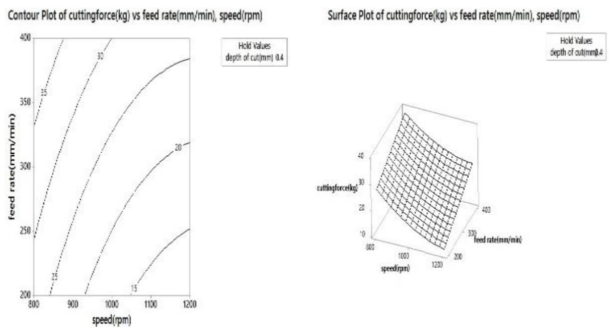

Fig. 8: Cutting force for feed rate vs. Speed

Table 3: Analysis of variance: 2nd order equation

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Modal	11	2754.32	250.39	4.53	0.021
Blocks	2	152.80	76.40	1.38	0.305
Linear	3	2008.90	669.63	12.11	0.002
Speed (rpm)	1	532.90	532.90	9.64	0.015
Fd. rate(mm/min)	1	435.60	435.60	7.88	0.023
Cut depth (mm)	1	1040.40	1040.40	18.82	0.002
Square	3	333.67	111.22	2.01	0.191
$Speed^2$	1	19.09	19.09	0.35	0.573
Feed $rate^2$	1	0.07	0.07	0.00	0.972
Depth of cut^2	1	137.86	137.86	2.49	0.153
2-way interaction	3	387.38	129.13	2.49	0.150
Speed*feed rate	1	6.12	6.12	0.11	0.748
Speed *cut depth	1	210.13	210.13	3.80	0.117
Fd. rate*cut depth	1	171.13	171.13	3.10	0.117
Error	8	442.22	55.28		
Lack of cut	5	442.22	88.44	*	*
Pure error	3	0.00	0.00		
Total	19	3196.55			

Table 2: Theoretical vs. Experimental results: 2nd order equation

Speed (rpm)	Feed rate (mm/min)	Depth of cut (mm)	Cutting force(kg)	
			Theoretical	Experimental
800	300	0.4	30.9421	35
1000	300	0.4	20.9767	22
1000	300	0.2	19.06832	37
1200	300	0.4	16.3449	29
1000	400	0.4	26.9936	33
1000	300	0.6	37.21844	36
1000	300	0.4	20.9767	22
1000	200	0.4	15.2932	26
1200	400	0.2	22.20342	18
1200	200	0.6	16.65314	17
1000	300	0.4	20.9767	22
1000	300	0.4	20.9767	22
800	200	0.2	23.35022	19
800	400	0.6	61.70074	68
1200	200	0.2	17.25302	11
1000	300	0.4	20.9767	22
800	400	0.2	24.80062	23
800	200	0.6	43.25034	46
1200	400	0.6	38.60354	43
1000	300	0.4	20.9767	22

5. Conclusion

The first order differential equation for the cutting force prediction from ANOVA shows that depth of cut is the high influential parameter in the cutting force analysis. The cutting force is increased by high depth of cut followed by high feed rate and finally low cutting speed. Then in the case of second order equation of the cutting force prediction from ANOVA, the combination of high depth of cut and the feed rate gives higher increase in the cutting speed and very high tool wear. The cutting force is decreased by increasing the speed of the process and decreasing the feed rate and the depth of cut. It was found that the cutting speed was the dominant factor followed by the cutting feed rate and the axial depth of cut. It was also observed that high cutting speed, low cutting feed rate and low axial depth of cut gave lower cutting force.

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