Experimental Investigation of machining parameters on milling by using full factorial design

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Abstract— In a machining process, in order to improve machining efficiency, reduce the machining cost, and improve the quality of machined parts, it is necessary to select the most appropriate machining conditions. The present experimental investigation of the influence of cutting parameters (speed, feed, and depth of cut) on cutting forces and Material removal rate (MRR) has been analyzed in a Milling machine. Under the different cutting conditions (variable), and finding the responses. Experimental were conducted on tool dynamometer and the influence of cutting parameter was studied using analysis of variance (ANOVA) based on adjusted approach. Based on the main effects plots obtained through Full Factorial design, a total of 27 tests were carried out, optimum level for MRR and cutting force were chosen from the three levels of cutting parameters considered. The range of each parameter is set at three different levels, namely low, medium and high. Mathematical models were deduced by software MINITAB in order to express the influence degree of the main cutting variables such as cutting speed, feed rate and depth of cut on cutting force components. The results indicate that the depth of cut is the dominant factor affecting cutting force components. The depth of cut influences tangential cutting force more than radial and axial forces. The cutting speed affects tangential force more than radial and axial forces.

Keywords: Cutting Force, Material Removal Rate, Full Factorial Design, ANOVA, Milling

1. INTRODUCTION

The service life of any workpiece depends on its properties of the force and removal rate, because this is with the direct contact of atmosphere, so the performance of any forces may get affected because of the physical and chemical change in the surface. There is a high demand of components of aluminium alloys of better finishing in the aerospace industries in order to increase their performance by avoiding presence of some stress concentrators in the surface, such as micro cracks, scratches, or striations produced during machining.Increasing the productivity and the quality of the machined parts are the main challenges of manufacturing industries. This objective requires better management of the machining system. This literature includes information on hard materials, soft materials, and soft and abrasive materials used in turning, coating materials for cutting tools, wear observed during turning operations and surface finish of the machined work piece. The machining with titanium-nitride coated carbide tool at 0.18 mm/rev and DOC of 1.5 mm resulted in greater amount of both tangential (Pz) and axial force (Px) than that uncoated carbide tools [1]. There was not variation of forces for both types of tool at lower feed rate of 0.095 mm/rev. Machining of Steel 3 type required lesser force compared to other two grades of cast austenitic stainless steel [2].Machining at low cutting speed and at high feed rates the chip of low curl radii was obtained with high chip thickness [3].The chip curl radius and chip thickness increases with increase in the cutting speed. At lower cutting speed the chips obtained is of yellow color, brittle color chips are obtained at higher speed [4-5].With increase in both cutting speed and the feed rate there occurred a transition of chip to segmented type from continuous type [5-9].

The influence of cutting parameters (speed, feed, and depth of cut) on cutting forces and surface finish has been analyzed, under the different variable with different responses. 27 experiments based Full Factorial design was used to study cutting force (Fx, Fy and Fz) and Material removal Rate (MRR) of mild steel work-piece. Full Factorial function was adopted to optimize the milling process with multiple performance characteristics. The machining parameters setting of were found by using ANOVA for analysis of variance table for maximum cutting force and minimum MRR.

2. EXPERIMENTAL SET-UP

In this unit detail methodology of the experiment has been described. The detail aspect of machine tool used, equipment facilities, work piece material, cutting tool, machining parameters and experimental set-up has been discussed. The Milling Machine is shown in Fig.1.

Fig 1 Milling Machine

3. DESIGN OF EXPERIMENT

The present experimental investigation deals with the analysis of the experiment by the Full Factorial methodology. . Based on the main effects plots obtained through Full Factorial design, a total of 27 tests were carried out,optimum level for MRR and cutting force were chosen from the three levels of cutting parameters considered. Machining parameters and their levels are shown in Table 1. The range of each parameter is set at three different levels, namely low, medium and high. Mathematical models were deduced by software design Expert in order to express the influence degree of the main cutting variables such as cutting speed, feed rate and depth of cut on cutting force components experiments with combination of different cutting parameters were randomly repeated. The 3^3= 27 experiments of settings were done to analyse the response that is the Cutting force and Material removal rate.

Table 1 Machining parameters and their levels

Parameters	Symbol	Levels		Unit
		Low	High	
Feed	F	16	40	mm/min
Speed	S	45	90	RPM
Depth of Cut	d	0.1	0.2	mm

4. RESULTS AND DISCUSSIONS

Table 2 presents' experimental results of cutting force components (Fx, Fy and Fz) for various combinations of cutting regime parameters (cutting speed, feed rate and depth of cut) according to 3^3full factorial design. The results indicate that the lower cutting forces were registered at the higher cutting speeds. This can be related to the temperature increase in cutting zone and leads to the drop of the work piece yield strength and chip thickness. The results also show that cutting forces increase with increasing feed rate and depth of cut because chip thickness becomes significant what causes the growth of the volume of deformed metal. That means increasing of cutting speed with lowest feed rate and depth of cut leads to decreasing of cutting force components.

Table 2 Observation table

Run no.	Center Pt	Blocks	S	F	d	Fx	Fy	Fz	MRR
1	1	1	45	16	0.1	957	74	1041	5.42
2	1	1	90	40	0.1	545	215	924	7.35
3	1	1	90	16	0.2	178	168	557	6.54
4	1	1	45	40	0.2	1426	89	1149	5.75
5	1	2	90	16	0.1	619	176	511	6.68
6	1	2	45	40	0.1	1170	97	1257	5.94
7	1	2	45	16	0.2	962	49	990	5.37
8	1	2	90	40	0.2	178	197	957	6.95

5. ANALYSIS OF Fx

Fig 2 gives the main factor plots for Fx. Axial force Fx appears to be a decreasing function shown in same figure. This figure also indicates that Fx is an almost linear increasing function of d. But the feed rate f has a little effect on Fx. The results of analysis of variance (ANOVA) for axial force Fx are shown in Table 3 This table also shows the degrees of freedom (DF), F-values means ratio of variance and probability (P-VAL.) each factor and different interactions . A low P-value (≤0.05) indicates statistical significance for the source on the corresponding response (i.e., α = 0.05, or 95% confidence level), this indicates that the obtained models are considered to be statistically significant, which is desirable; as it demonstrates that the terms in the model have a significant effect on the response. The other important coefficient, R-Squared, which is called coefficient of determination in the resulting ANOVA tables, is defined as the ratio of the explained variation to the total variation and is a measure of the fit degree. When R-Squared approaches to unity, it indicates a good correlation between the experimental and the predicted values.

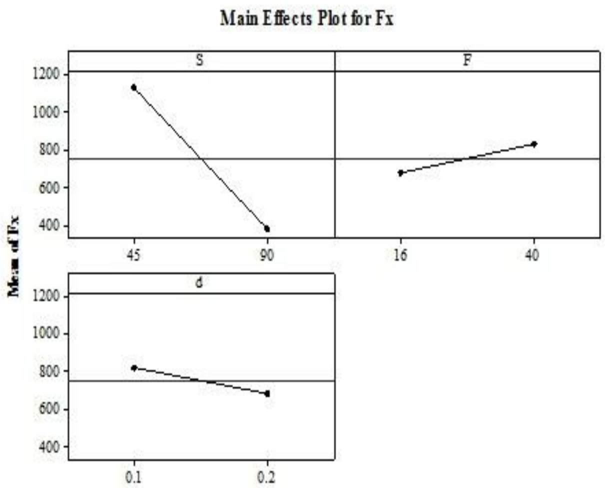

Fig 2 Main Effect plots for Fx

Table 3 Analysis of Variances of Fx

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Blocks	1	3916	3916	3916	0.05	0.834
Main Effects	3	1204105	1204105	401368	5.32	0.102
S	1	1121253	1121253	1121253	14.85	0.031
F	1	45451	45451	45451	0.60	0.494
d	1	37401	37401	37401	0.50	0.532
Residual Error	3	226548	226548	75516		
Total	7	1434570				

6. ANALYSIS OF Fy

Fig 3 shows the main factor plots for Fy. Radial force Fy appears to be a decreasing function of Vc. This figure also indicates that Fr is an almost increasing function of d. But feed rate f has a little effect on Fr.

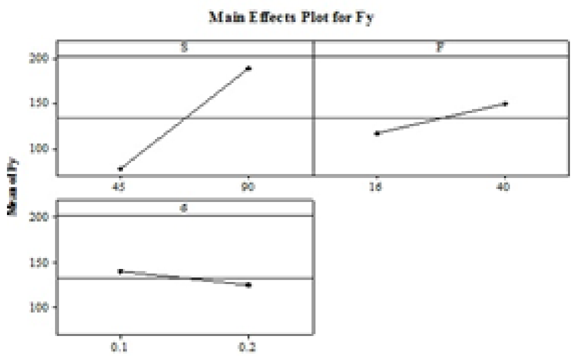

Fig 3 Main Effect plots for Fy

Table 4 Analysis of Variances of Fy

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Blocks	1	87.6	87.6	87.6	15.77	0.029
Main Effects	3	27399.8	27399.8	9133.3	1643.51	0.000
S	1	24804.3	24804.3	24804.3	4463.50	0.000
F	1	2145.1	2145.1	2145.1	386.01	0.000
d	1	450.3	450.3	450.3	81.03	0.003
Residual Error	3	16.7	16.7	5.6		
Total	7	27504.1				

7. ANALYSIS OF Fz

Fig 4 highlights the main factor plots for Fz. Tangential cutting force Fz appears to be an almost decreasing function of Vc. This figure also indicates that Ft is an almost linear increasing function of f and d respectively.

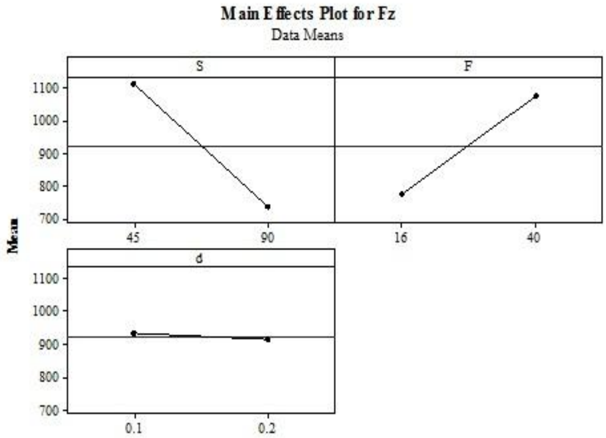

Fig 4 Main Effect plots for Fz

Table 5 Analysis of Variances of Fz

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Blocks	1	242	242	242	0.02	0.889
Main Effects	3	453986	453986	151329	14.33	0.028
S	1	276768	276768	276768	26.21	0.014
F	1	176418	176418	176418	16.71	0.026
d	1	800	800	800	0.08	0.801
Residual Error	3	31673	31673	10558		
Total	7	485901				

8. ANALYSIS OF MRR

Fig 5 highlights the main factor plots for MRR. MRR appears to be an almost linear decreasing function of Vc. This figure also indicates that MRR is an almost linear increasing function of f and d respectively.

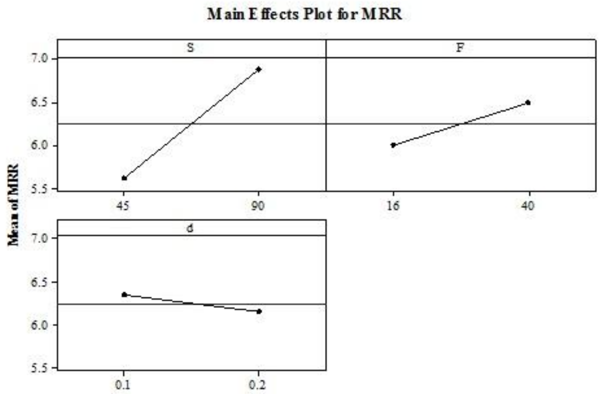

Fig 5 Main effect plots for MRR

Table 6 Analysis of Variances of MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Blocks	1	0.00180	0.00180	0.00180	0.15	0.722
Main Effects	3	3.74130	3.74130	1.24710	105.99	0.002
S	1	3.17520	3.17520	3.17520	269.85	0.000
F	1	0.49005	0.49005	0.49005	41.65	0.008
d	1	0.07605	0.07605	0.07605	6.46	0.085
Residual Error	3	0.03530	0.03530	0.01177		
Total	7	3.77840				

9. CONCLUSIONS

Full Factorial Design method is found to be a successful technique to perform trend analysis of Cutting Force and MRR in metal cutting in milling with respect to various combinations of design variables (cutting speed, feed rate, and depth of cut).Response model for Fz is more precise than first Response model for Fx and second Response model for Fy in predicting the power consumption.

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