Journal of Manufacturing Technology and Research (An International Journal)| Volume 11 | Issue 1-2 | Month Jan-Dec(2018) ISSN: 0973-0281

Optimization of process parameters for cutting force and surface roughness of a tie rod component

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Abstract

Surface finish and cutting force of a machined component, are undoubted, factors that significantly affect its functionality and service life. A judicious selection of machining parameters like cutting speed, feed, depth of cut etc. is a key decision that has to be made to achieve the required surface finish and cutting force. In the present work, we analyzed the effect of these parameters on cutting force and surface roughness of a tie rod mild steel component machined on a lathe machine. A popular statistical approach namely Taguchi's design of experiment was employed to determine optimum values of process parameters for a given set of conditions and desired response variables. A suitable orthogonal array L9 was used, and signal-to-noise (S/N) ratio was calculated for each experimental run. The response variables so obtained were used to determine the optimum setting of machining above parameters. The results show that the depth of cut effect cutting force significantly with 94.5% as compared to other parameters and feed rate effect surface roughness significantly with 92.25%. We finally compared the obtained results with a confirmation experiment.

Keywords: Design of Experiments; Taguchi Method; Orthogonal Array; S/N Ratio.

1. Introduction

In the current environment, quality is a key approach for all manufacturing sectors to compete in the global market. There is a need for industries to satisfy the customers with a higher quality of the product in minimum cost. The product quality is influenced by machining parameters and working environments. The geometry of tools, the coating of inserts, machine control parameters, cooling and lubrication systems have been identified as the variables which affect the quality and manufacturing costs of the products.

Initially, traditional experimental design procedures were used to optimize the process variables, but these methods are very difficult to perform when the number of variables and levels are large. Due to the increase in variables, the number of experimental runs is required, which results in extended time and resources. The Taguchi proposed a unique design of experiment matrix which also called orthogonal arrays to the identified effect of controllable factors and non-controllable factors on the response variables with less number of experimental run [2]. Taguchi experimental designs are extensively used to study the behaviour of a given process outcome depending upon various parameters [3]. In this method, the less number of experimental runs are required with less experiment time in reduced cost to identify the significant factors. In the present study, the effect of process parameters on cutting force and surface roughness of a mild steel component machined on a lathe machine was analyzed.

2. Literature Review

Various methods, such as the regression analysis and conventional optimization techniques have been implemented by researchers in developing the mathematical model and optimizing machining attributes for limited parameters. Various techniques like Taguchi method, response surface methodology (RSM), and weighted principle component analysis (WPCA) are used for a large number of variables [4–6].

A study was carried out on the effects of cutting speed and feed rate on tool wear, and surface roughness of machined SiC-p reinforced aluminium metal matrix composite. Better surface quality was observed with higher cutting speed and lower feed rates [7]. In a study on the intrinsic relationship between tool flank wear and operational conditions in metal cutting processes using carbide cutting inserts it was revealed that cutting speed affects tool life more significantly than feed rate [8]. Taguchi approach was used to optimize process parameters for end milling operation on hardened steel. After analysis, it was observed that adhesion and chipping were the main causes of tool wear. Multiple regression analysis was applied for estimating the effect of machining variables on surface finish and tool wear. Cutting speed was found to be the most significant factor affecting surface finish and tool wear [9]. Correlation between surface roughness and cutting tool vibration for the turning operation was studied . The study concluded that the surface roughness of the product was observed to be affected significantly by vibrations due to the overhang of the cutting tool. Surface roughness was found to be increased with an increase in feed rate [10]. The effect of cutting speed, feed rate and depth of cut on surface roughness was analyzed in CNC turning operation of EN354 alloy steel with CNMG 120408 GT cutting tool. The Taguchi design of experiments was used in optimizing the process variables with the regression model and analysis of variance (ANOVA) for further analysis. It was found that surface roughness is significantly affected by the cutting speed. However, feed rate and depth of cut also affect the surface roughness to some extent [11]. The effects of cryogenic treatment and drilling variables on surface finish and hole quality in dry drilling operation on AISI 304 stainless steel were studied . Taguchi method was used to achieve better surface roughness and minimize roundness error while RSM was used to find the most significant variables affecting surface finish and roundness error. Experimental results showed that cutting speed and feed rate were the most significant factors affecting surface finish and roundness of the hole [12].

3. Methodology

In this study, the tie rod component was selected which has 20 mm diameter and 50 cm in length. The turning operation has been done on the lathe machine with single point cutting tool for experimental investigation. Cutting force and surface finish were taken as response variables for the finished components. Objectives of the study are as:

1. To find the process parameter which has a more significant effect on cutting force and surface finish of the tie rod product in turning operation.
2. To optimize the machining variables for cutting force and surface finish.

The following steps have been done in this study.

a) Identification of various control factors
b) Selection of Taguchi orthogonal array for an experimental run
c) Experiment runs and surface finish and cutting force measurement
d) Analyze the results of experiments; (S/N ratio)
e) ANOVA analysis
f) Confirmation experiment

3.1. Identification of control factors

There are two factors in every experiment which are responsible for variations in the process.

The control factors that affect the response variables on a lathe machine are identified as Cutting speed (rpm), Feed rate (mm/min) and Depth of cut (mm). The various noise factors affecting response variables are vibration, raw material variation and machine condition etc. These noise factors are not considered as process parameters in the Taguchi design of experiments. The various control factors and their selected levels are shown in Table1.

Table 1. Control factors and levels

Control Factors	Levels		
	A	B	C
Cutting speed (rpm)	120	180	240
Feed rate (mm/min).	45	60	75
Depth of cut (mm)	0.5	0.75	1.0

3.2. The selection of orthogonal array

The selection of orthogonal array depends upon the degrees of freedom. The total degree of freedom for the study is seven which is as follows, 1 for mean value and 6 for factors and their levels (2x3), L9 array orthogonal array was found appropriate for experimentation. So L9 orthogonal array is selected for experiment runs. The L9 array is required 9 experiments to find out the effect of process variables on the response variables and also to optimize the parameters.

Table 2. L9 orthogonal array for experiment runs

Experiment Run	Cutting speed (rpm)	Feed rate (mm/min)	Depth of cut (mm)
1	120	45	0.5
2	120	60	0.75
3	120	75	1.0
4	180	45	0.75
5	180	60	1.0
6	180	75	0.5
7	240	45	1.0
8	240	60	0.5
9	240	75	0.75

3.3. Experiment run and measurement

Experiments are done on engine lathe according to Taguchi orthogonal array. Surface finish and cutting force are two response variables measured during each experiment run. The cutting force is measured by lathe tool dynamometer while surface roughness tester is used to measure the surface finish.

Table 3.Output Response and S/N ratios for cutting force and surface roughness

Experiment Run	Cutting speed (rpm)	Feed rate (mm/min)	The depth of cut (mm)	Cutting Force (kgf)	Surface Roughness(Ra)	S/N ratio for cutting force	S/N ratio for surface roughness

1	120	45	0.5	20	1.25	-26.0206	-1.9382
2	120	60	0.75	38	3.12	-31.5957	-9.88309
3	120	75	1.0	48	4.56	-33.6248	-13.1793
4	180	45	0.75	32	1.45	-30.103	-3.22736
5	180	60	1.0	47	2.69	-33.442	-8.59505
6	180	75	0.5	18	4.12	-25.1055	-12.2979
7	240	45	1.0	42	1.89	-32.465	-5.52924
8	240	60	0.5	12	3.87	-21.5836	-11.7542
9	240	75	0.75	36	4.58	-31.1261	-13.2173

3.4. Analysis of the S/N Ratio

The variability in the experimental results and mean of results are analysis with the help of Signal to Noise (S/N) ratio. The value of S/N ratio greatly depends on the quality attributes of the process or product which require optimization of process variables. Three types of performance measures, lower-the-better, the higher-the-better and the nominal-the-better are used in the S/N ratio analysis. In the present study function, "smaller the better" is used for optimizing the cutting force and surface roughness. The levels which have the highest S/N ratio are selected as the optimized value for the corresponding factors. The mathematical formula for S/N ratio is shown in equation1.

$S/N = -10 \log((l/n)(\Sigma y2))$……………(1)

Minitab software is used to analysis the S/N ratio of cutting force and surface roughness with three machining variables individually. In the main effects graphs, X-axis indicates the values machining variables and Y-axis denotes the output response. These plots are suitable to find optimum conditions for the response variable.

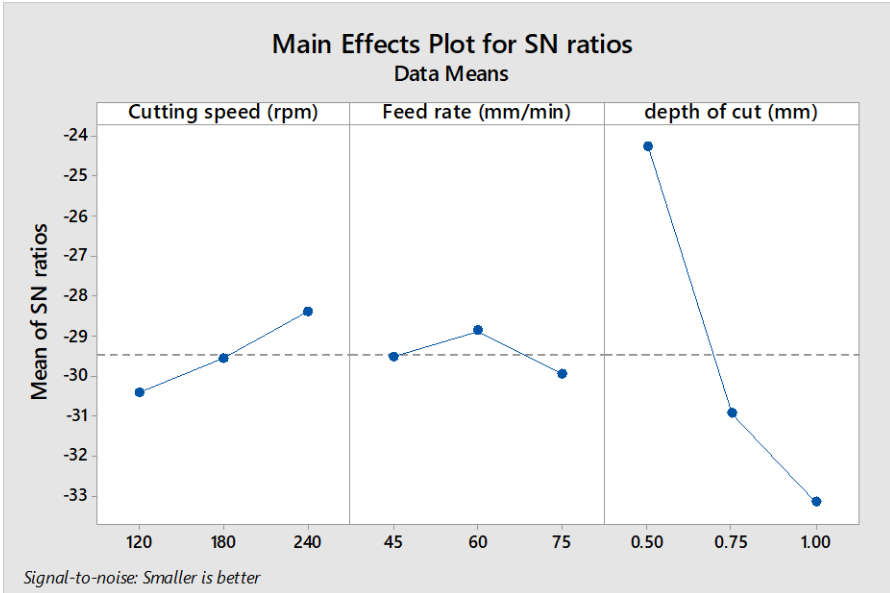

Figure 1(a). Main effect plots for S/N ratios for cutting force

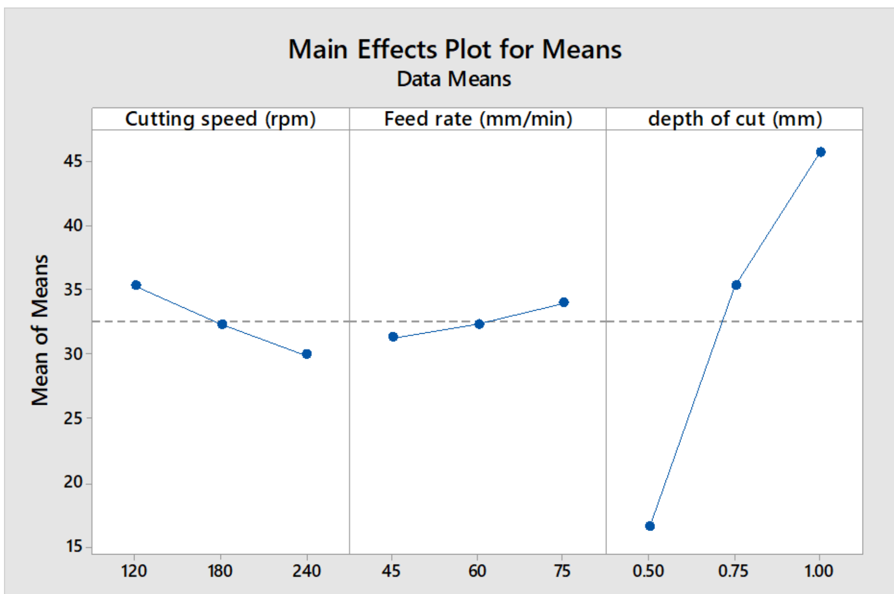

Figure 1(b). Main effect plots for means for cutting force

Figure 1(a) & (b) show that the main effect plots for cutting force, the graph shows that increase in cutting speed, decreases the cutting force but it increases with increase in feed rate. It is found that an increase in the depth of cut, increases the cutting force significantly.

Table 4. S/N ratios for cutting force (Smaller the best)

Level	Cutting speed (rpm)	Feed rate (mm/min)	depth of cut (mm)
1	-30.41	-29.53	-24.24
2	-29.55	-28.87	-30.94

3	-28.39	-29.95	-33.18
Delta	2.02	1.08	8.94
Rank	2	3	1

Table 4 gives the values for the S/N ratio of different machining parameters for smaller is the better function. The depth of cut significantly dominates the machining compared to other parameters.

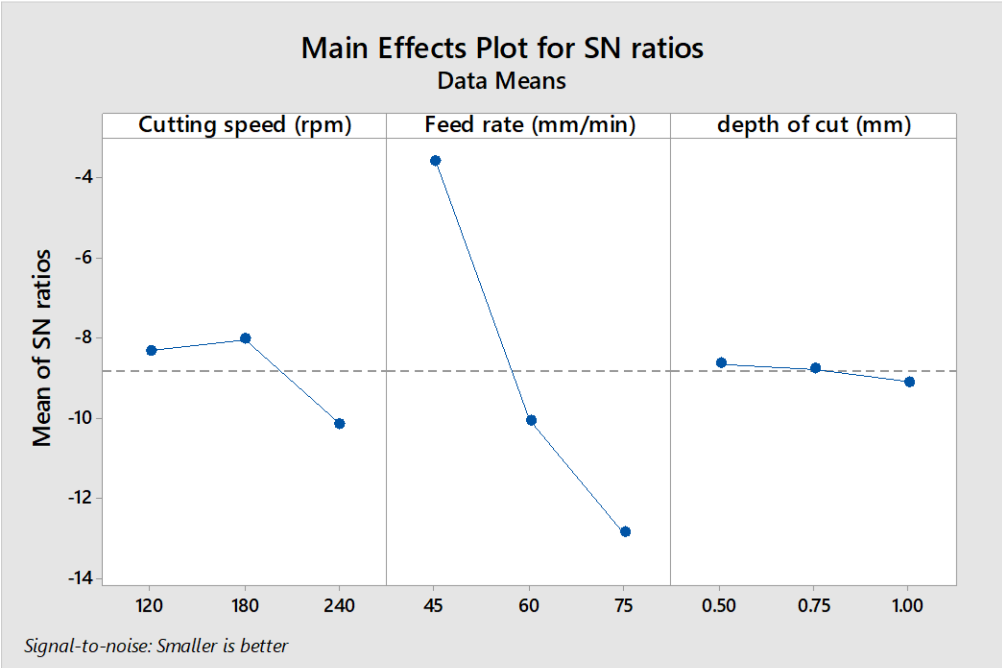

Figure 2(a). Main effect plots for S/N ratios for surface roughness

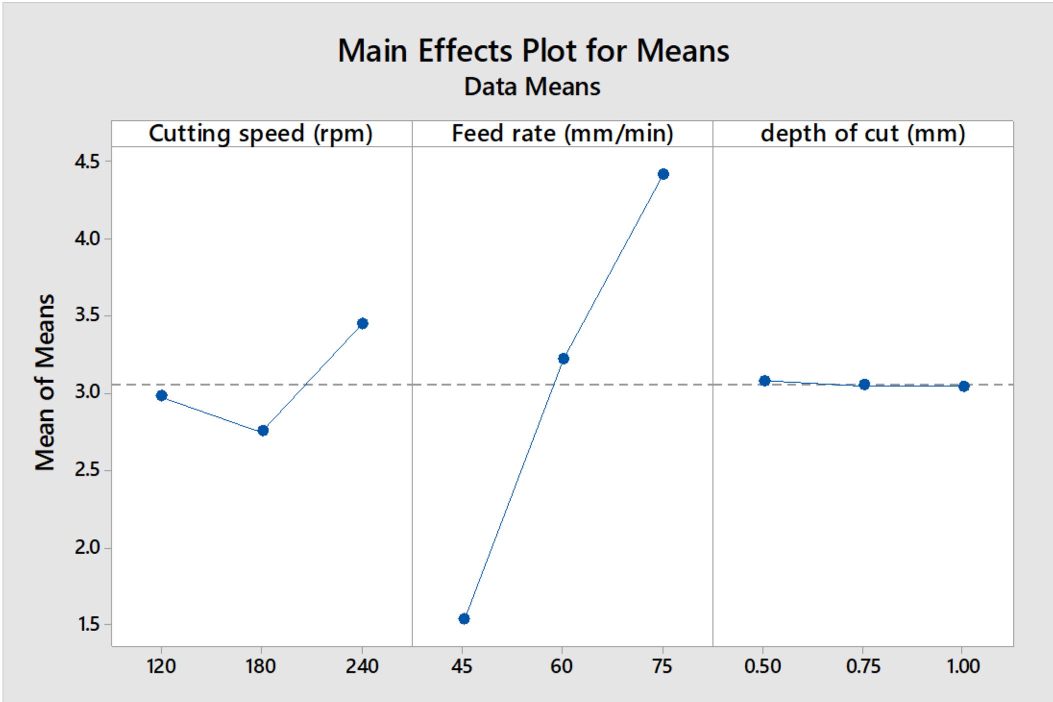

Figure 2(b). Main effect plots for means for surface roughness

Figure 2(a) & (b) show that the main effect plots for surface roughness, As the plot, indicates an increase in cutting speed, increases the surface roughness. The significant increase in the surface roughness is seen with the corresponding increase in the feed rate.

Table 5.Response Table for Signal to Noise Ratios for surface roughness (Smaller the best)

Level	Cutting speed (rpm)	Feed rate (mm/min)	depth of cut (mm)
1	-8.334	-3.565	-8.663
2	-8.040	-10.077	-8.776
3	-10.167	-12.898	-9.101
Delta	2.127	9.333	0.438
Rank	2	1	3

The table 5 shows that the rvalue of S/N ratio at various levels of machining variables for smaller is the better function. The feed rate significantly dominates the machining compared to other parameters.

Table 6. Optimal Conditions

Optimal parameters for turning mild steel			
	Cutting speed (rpm)	Feed rate (mm/min)	depth of cut (mm)
Cutting Force (kgf)	240	60	0.5
Surface Roughness(Ra)	180	45	0.5

3.6. Analysis of variance (ANOVA) analysis

ANOVA is a technique which investigates the effect of individual process parameters on response magnitude. ANOVA checks the level of impact of process variables on responses at a different trial.T he ANOVA table is consists of sum squares (SS), mean squares (MS), the degree of freedom (DOF), P-value, F-value and percentage contribution of each factor.

Table 7. ANOVA analysis for cutting force

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Cutting speed (rpm)	2	42.89	21.444	2.12	0.320	3.13
Feed rate (mm/min)	2	10.89	5.444	0.54	0.650	0.79
Depth of cut (mm)	2	1296.22	648.111	64.10	0.015	94.5
Error	2	20.22	10.111			1.47
Total	8	1370.22				100

Table 7 shows the ANOVA analysis; it gives the contribution of the individual process variable. From the ANOVA table, it can be concluded that the depth of cut effect cutting force significantly with 94.5% as compared to other parameters.

Table 8. ANOVA analysis for surface roughness

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Cutting speed (rpm)	2	0.7515	0.37574	2.43	0.292	5.47
Feed rate (mm/min)	2	12.6548	6.32741	40.91	0.024	92.25

Depth of cut (mm)	2	0.0020	0.00101	0.01	0.994	0.014
Error	2	0.3094	0.15468			2.25
Total	8	13.7177				100

Table 8 shows the contribution of the individual process parameter. ANOVA table shows that the feed rate affects the surface roughness significantly with 92.25% as compared to other parameters.

3.7. Confirmation experiment

The final step of the study is to conduct the confirmation tests to authenticate the optimum values of the control factors obtained from the analysis of experimental runs. In the present study, confirmation experiments are conducted for turning mild steel work piece and found that results are good.

4. Conclusion

It is found that the Taguchi design of the experiment is very useful to optimize the process variables when there is less time to conduct experiments. It provides a systematic methodology with a less number of experimental runs, when compared with full factorial analysis and found similar results. In this experimental study, Taguchi's method is selected to find out the optimal cutting variables in the turning operation of the mild steel tie rod component. The experimental test results are evaluated by the ANOVA analysis. The results show that the depth of cut effect cutting force significantly with 94.5% as compared to other parameters and feed rate effect surface finish significantly with 92.25% as compared to other parameters.

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