Analyzing the Effect of Overhang Length on Vibration Amplitude and Surface Roughness in Turning AISI 304

Farhana Dilwar, Rifat Ahasan Siddique

Abstract*— In this paper, the experimental investigation is carried out to assess the effect of overhang length on two important responses - vibration amplitude and surface roughness by using response surface methodology (RSM) and main effects plot. For this purpose, we used workpiece of AISI 304 material and the vibration amplitude and surface roughness of the workpiece are determined through experiments using constant depth of cut (1 mm) with different cutting speed, feed rate, and tool overhangs. Based on different tool overhangs under different cutting parameters, the impact of overhang length on vibration amplitude and surface roughness in turning process is studied. Then the optimized value of overhang length is suggested by Desirability Function Analysis (DFA) to get the minimum vibration amplitude and better surface quality. The 3D response graphs present how tool overhangs affect vibration amplitude and surface roughness. From main effects plot, it is evident that minimum overhang length gives the better quality machining performance.

***Index Terms*— AISI 304, Turning, Overhang Length, Response Surface Methodology (RSM), Desirability Function Analysis, Main Effects Plot, Vibration Amplitude, Surface Roughness.**

◆

1 Introduction

Turning is a form of machining, a material removal process, which is used to create rotational parts by cutting away unwanted material. Turning operation using a single point cutting tool has been one of the oldest and popular methods of metal cutting. It has even replaced grinding in several applications with reduced lead time without affecting the surface quality. In turning, it is important to find out the appropriate parameters to obtain the high cutting performance. In this connection, two important aspects which are widely studied in turning operations are vibration amplitude and surface roughness of the work-piece. Present manufacturing industries are facing difficulties due to vibrations and poor surface qualities.

Overhang length of the tool holder has a great significance along with the machining parameters (Cutting speed, feed rate, and depth of cut). Tool overhang is a cutting tool parameter that has not been investigated in as much detail as some of the better-known ones. Based on previous researches and theories, it is concluded that cutting tools should be clamped as short as possible to achieve the better surface finish and minimum vibration amplitude.

In our research, we investigated the effect of the overhang length of the cutting tool holder on vibration amplitude and surface roughness using Response Surface Methodology (RSM) and Main Effects Plot. From 3D response graph, it can be clearly observed the changes in vibration amplitude and surface roughness with the change of overhang length.

2 Literature Review

In a turning operation, it is important to select cutting parameters so that high cutting performance can be achieved. Selection of desired cutting parameters by experience or using handbook does not ensure that the selected cutting parameters are optimal for a particular machine and environment [1].

According to B. A. G. Yuvaraju [2], vibrations produced in machine tools like lathe, milling, and grinding, etc. during machining operation are one of the primary concern in manufacturing industries. These vibrations not only increase the surface roughness of workpiece but also affect the tool life and noise during the machining operation.

Surface quality of machined workpieces is one of the most important parameters in machining processes. It is highly influenced by machine vibrations because chatter vibrations cause poor surface qualities [3].

Murat Kiyak [4] investigated the effects of changes in the tool overhang in the external turning process on both the surface quality of the workpiece and tool wear. He observed that the surface roughness of workpiece increases as the tool overhang increases. Using the same tool overhang, the surface roughness of the workpiece increases as the DOC increases.

Zhenyu Zhao [5] said that the increased amount of tool overhang is bound to lead to reduced tool stiffness, especially in the processing of hardened steel and other relatively high hardness materials difficult to machine tooling, tool used to select a small amount of overhang length. Clamp installation tool shank part as much as possible, can improve the tool rigidity, reducing vibration so that the cutting process more stable and less tool wear. Tool overhang increases, less rigid cutting tools, bending deformation is increasing, prone to vibrations in the milling process, the surface of the workpiece processing ripple, leaving the processing trace on processing quality and accuracy.

K. KHALILI [6] studied the relations between tool overhang and vibration signal. The result of his paper shows that vibration signal increase with increased tool overhang.

Gaurav Bartarya [7] used a full factorial design of experiments procedure to develop the force and surface roughness regression models, within the range of parameters selected. The regression models developed show that the dependence

International Journal of Scientific & Engineering Research, Volume 9, Issue 6, June -2018
IISSN 2229-5518

of the cutting forces i.e. cutting, radial and axial forces and surface roughness on machining parameters are significant, hence they could be used for making predictions for the forces and surface roughness.

R. Suresh's [8] paper deals with developing a response surface method as a function of cutting parameters in turning AISI H13 steel to correlate the machining parameters with tool wear and surface roughness. The developed RSM models exhibited better proximity between predicted values and experimental values with 95% confidence intervals. The results imply that the model can be used easily to forecast tool wear and surface roughness in response to cutting parameters. Suleyman Neseli [9] suggested that the RSM developed model can be effectively used to predict the surface roughness in turning operation.

Priyabrata Sahoo [10] used response surface methodology (RSM) for surface roughness (Ra) and tool vibration (dB) optimization. The method used in his study has been proven as an effective tool for the analysis of the turning process.

From the above literature reviews, it is revealed that overhang length of tool holder has a great impact on vibration amplitude and surface roughness. But the number of researches about overhang length is very limited. The objective of this paper thereby is, to analyze the influence of tool holder overhangs on vibration amplitude and surface roughness in turning using response surface methodology (RSM) and main effects plot.

3 Experimental Condition and Planning of Experiment

The experimental instruments and cutting conditions have been summarized into the following table (Table 1).

TABLE 1
EXPERIMENTAL CONDITIONS

Machine Tool	Engine Lathe (Model: CS6266B)
Workpiece Material	AISI 304
Cutting Tool Holder	Carbon Steel
Cutting Tool Name	Single point side cutting tool
Cutting Tool Material	Coated Carbide
Cutting Environment	Dry
Surface Roughness Measuring Equipment	Surface Roughness Tester
Vibration Amplitude Measuring Equipment	Sound Level Meter

TABLE 2
SELECTION OF MACHINING PARAMETER AND THEIR DESIGN CRITERIA

Factor	Name	Units	Minimum	Maximum
A	Cutting Speed	m/min	50.00	100.00
B	Feed Rate	mm/rev	0.1000	0.2000
C	Overhang length	mm	35.00	65.00

3.1 Experimental Layout

The experimental layout plan (Table 3) is established using Response Surface Methodology (RSM) in Design Expert 11.0 Software. The experiments have been done with the values of these three inputs. Full factorial design with 20 runs is used. RSM can be conducted by two methods- Box-Behnken and Central Composite Design (CCD). Here, CCD method is used.

TABLE 3
EXPERIMENTAL LAYOUT OF INPUT PARAMETER AND THEIR RESULTAN OUTPUT

Factor 1 **A:Cutting Speed**	Factor 2 **B:Feed Rate**	Factor 3 **C:Overhang length**	Response 1 **Vibration Amplitude**	Response 2 **Surface Roughness**
m/min	mm/rev	mm	dB	μm
75	0.1	50	73.03	1.277
50	0.1	35	70.31	1.171
75	0.15	50	72.77	1.253
75	0.15	50	71.67	1.232
100	0.1	65	75.74	1.383
50	0.1	65	74.43	1.204
75	0.15	35	70.68	1.241
100	0.2	35	71.04	1.314
75	0.15	65	74.78	1.275
75	0.15	50	71.79	1.255
100	0.15	50	73.39	1.348
75	0.2	50	72.44	1.241
75	0.15	50	72.76	1.237
50	0.2	65	73.84	1.168
100	0.1	35	71.63	1.349
100	0.2	65	75.15	1.347
50	0.2	35	69.73	1.135
75	0.15	50	71.98	1.281
50	0.15	50	72.08	1.169
75	0.15	50	72.73	1.259

3.2 Experimental Setup

The experimental setup of our turning operation has been presented in Figure 1. Initially, the cutting tool holder with carbide insert has been fixed at a certain overhang length according to the experimental layout which is found from Design Experiment on the tool post of lathe and AISI 304 workpiece has been mounted on the headstock. A sound level meter has been fixed in a place by which vibration amplitude in decibel values are found. After that, the turning operation is performed on the lathe by changing RPM, feed rate, and overhang length at constant depth of cut (1 mm). Vibrations induced during machining are measured by the sound level meter and analyzed. Further, the surface roughness of workpiece is measured using Surface Roughness Tester SRG-4500(phase II).

International Journal of Scientific & Engineering Research, Volume 9, Issue 6, June -2018
IISSN 2229-5518

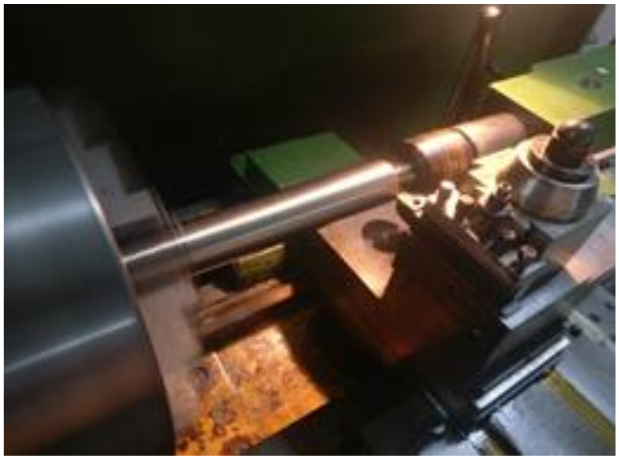


Fig. 1. Experimental Setup in turning AISI 304

3.3 Experimental Investigation

Response surface methodology (RSM) is employed to develop the model equations for the responses i.e. vibration amplitude in decibel and surface roughness of machined part as a function of input variables.

Response Surface Methodology (RSM) is a collection of mathematical and experimental techniques that requires sufficient number of experimental data to analyze the problems and to develop mathematical models for several input variables and output performance characteristics.

After completing the machining work, all the experimental data for the outputs are inserted into the experimental layout found from response surface methodology. Then Analysis of variance (ANOVA) is conducted to determine the result (P-Value) that independent variables (cutting speed, feed rate, overhang length) have on the dependent variables through a regression study and check the model is significant or not. In the experimenters based mathematical model of Cutting Speed (Vc), Feed Rate (f) and overhang length (OL) are developed in terms of three process parameters, namely vibration amplitude and Surface Roughness (Ra).

$$Y_n = F(Vc, f, OL) + e_{ii} \quad (1)$$

Here, Yn is desired response (vibration amplitude, surface roughness) and F is the response function of cutting speed, feed rate and overhang length.

The output response are proposed using the fitted second-order polynomial regression model which is called quadratic model. The quadratic model of Y can be written as follows:

$$Y = a_0 + \sum_{i=1}^{k} a_i x_i + \sum_{i=1}^{k} a_{ii} x_i^2 + \sum_{i=1}^{k} a_{ij} x_i x_j \quad (2)$$

Here, Y represents the responses and x_i, x_j are the independent variables.

The influence of cutting parameters and their interaction effects are analyzed by using 3-D response graph. Desirability Function Analysis (DFA) shows the optimized results in terms of both responses.

After that, the main effects plot have been drawn to examine differences between level means for three factors. There is a main effect when different levels of a factor affect the response differently.

4 RESULTS AND DISCUSSIONS

After completing the experiment, the value of surface roughness and vibration amplitude (dB) have been measured. The values have been inserted into Response Surface Methodology (RSM) table and, then the further analysis are done.

4.1 Analysis of Variance (ANOVA)

An ANOVA test has been done to find out if the experimental results are significant or not. The analysis of variance is commonly used to summarize the test, the significance of the regression model, and test for significant on individual model coefficients. Here, it has been done for both responses (vibration amplitude and surface roughness).

TABLE 4
ANOVA TABLE FOR VIBRATION AMPLITUDE

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	**47.90**	**9**	**5.32**	**30.79**	**< 0.0001**	**significant**
A-Cutting Speed	4.30	1	4.30	24.90	0.0005	
B-Feed Rate	0.8644	1	0.8644	5.00	0.0493	
C-Overhang length	42.23	1	42.23	244.34	< 0.0001	
AB	0.0000	1	0.0000	0.0001	0.9934	
AC	0.0000	1	0.0000	0.0001	0.9934	
BC	0.0000	1	0.0000	0.0001	0.9934	
A²	0.0427	1	0.0427	0.2468	0.6301	
B²	0.0427	1	0.0427	0.2468	0.6301	
C²	0.0393	1	0.0393	0.2274	0.6437	
Residual	1.73	10	0.1728			
Lack of Fit	**0.3532**	**5**	**0.0706**	**0.2569**	**0.9190**	**not significant**
Pure Error	1.38	5	0.2750			
Cor Total	49.62	19				

The ANOVA results for vibration amplitude (Table 4) showed that the selected full factorial model is significant.

Model F-value of 30.79 implies that the model is significant. There is only a 0.01% chance that an F-Value this large could occur due to noise.

P-values less than .0500 indicate model terms are significant. In this case, Overhang Length (C) is a significant model term. Values greater than 0.1000 indicate the model terms are not significant. Here, the P-value is less than 0.0001. So, the model is significant.

The Lack of Fit F-value 0.2569 implies the Lack of Fit is not significant relative to the pure error. There is a 91.90% chance that a Lack of Fit F-value this large could occur due to noise.

International Journal of Scientific & Engineering Research, Volume 9, Issue 6, June -2018
IISSN 2229-5518

TABLE 5
ANOVA TABLE FOR SURFACE ROUGHNESS

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	**0.0860**	**9**	**0.0096**	**60.73**	**< 0.0001**	**significant**
A-Cutting Speed	0.0799	1	0.0799	507.89	< 0.0001	
B-Feed Rate	0.0032	1	0.0032	20.36	0.0011	
C-Overhang length	0.0028	1	0.0028	17.72	0.0018	
AB	1.250E-07	1	1.250E-07	0.0008	0.9781	
AC	1.250E-07	1	1.250E-07	0.0008	0.9781	
BC	1.250E-07	1	1.250E-07	0.0008	0.9781	
A^2	7.778E-06	1	7.778E-06	0.0494	0.8285	
B^2	0.0000	1	0.0000	0.0832	0.7789	
C^2	3.841E-06	1	3.841E-06	0.0244	0.8790	
Residual	0.0016	10	0.0002			
Lack of Fit	**0.0001**	**5**	**0.0000**	**0.0347**	**0.9989**	**not significant**
Pure Error	0.0015	5	0.0003			
Cor Total	0.0876	19				

The ANOVA results for surface roughness (Table 5) showed that the selected full factorial model is significant.

The Model F-value of 60.73 implies that the model is significant. There is only a 0.01% chance that an F-Value this large could occur due to noise.

P-values less than .0500 indicate model terms are significant. In this case, Cutting Speed (A), Feed Rate (B), and Overhang Length (C) are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. Here, the P-value is less than 0.0001. So, the model is significant.

4.2 Quadratic Model Equation

After analyzing the experimental data the regression equations are developed and are given as:

Vibration Amplitude=

+68.01203-0.003334*A-20.66712*B+0.084369*C-0.001000*A*B-0.0000033*A*C-0.001667*B*C+0.0000199*A^2+49.81818*B^2+0.000531*C^2 (3)

Surface Roughness =

+1.03329+0.003141*A-0.618985*B+0.000588*C+0.000100*A*B+0.00000033*A*C-0.000167*B*C+0.00000269*A^2+0.872727*B^2+0.00000525*C^2 (μm) (4)

4.3 Regression Co-efficient

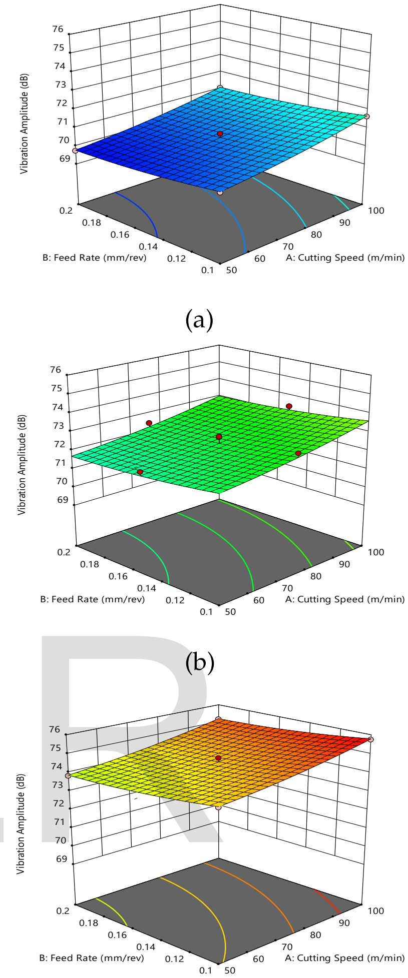
From the analysis of table 6, it is evident that capabilities of the regression based models, R^2 factors, are higher than 0.90. From table 6, it could be seen that P values are less than 0.05; hence the models are significant to 95% level of confidence.

TABLE 6
R^2 VALUES FOR VIBRATION AMPLITUDE AND SURFACE ROUGHNESS

Regression Co-efficient	Vibration Amplitude	Surface Roughness
R^2	0.9652	0.9820

4.4 3D Response Graphs

The influence of cutting factors on responses can be analyzed by using 3-D response graph.



(a) (b) (c)

Fig. 2. Variation in Vibration Amplitude at Overhang length (a) 35 mm (b) 50 mm (c) 65 mm

3-D response surface plots are drawn based on the regression equations (3) and (4) for the better understanding of interaction effects of independent variables on responses.

The response graphs are shown in Figure 2, for two varying parameters cutting speed and feed rate (v*f) by keeping the third parameter overhang length at three different level which indicates how vibration amplitude changes with overhang length. The vibration amplitude at 35 mm, 50 mm, 65 mm overhang length have been represented here. From the above three figures, minimum vibration amplitude is found in fig (a) which is 69.73 dB having shorter overhang length (35 mm). And the value increases with the increase of overhang length. Fig (c) indicates the maximum vibration amplitude (75.74 dB) where the overhang length is 65 mm. So, overhang length may

International Journal of Scientific & Engineering Research, Volume 9, Issue 6, June -2018
IISSN 2229-5518

be regarded as one of the major causes for such changes in vibration amplitude.

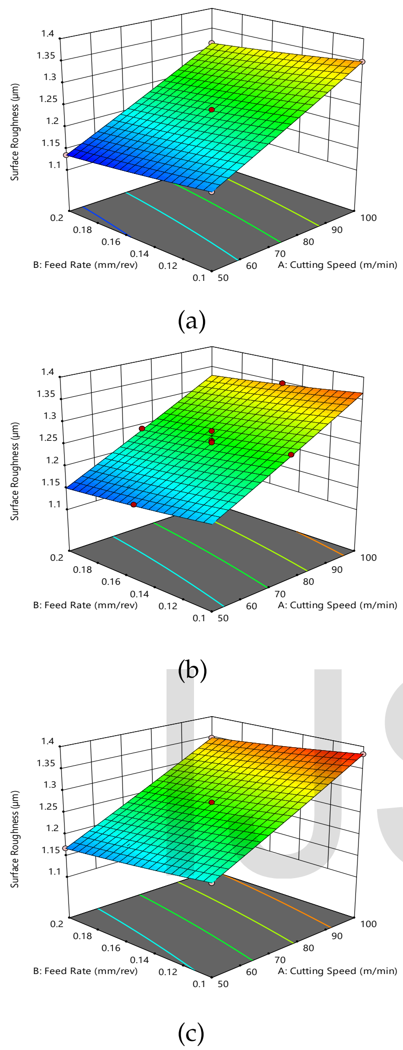


Fig. 3. Variation in Surface Roughness at Overhang length (a) 35 mm (b) 50 mm (c) 65 mm

The response graphs are shown in Figure 3, for two varying parameters cutting speed and feed rate (v*f) by keeping the third parameter overhang length at three different level which indicates how surface roughness changes with overhang length. 3D surface plot for surface roughness in terms of three different overhang length (35 mm, 50 mm, 65 mm) have been represented in Figure 3. These figures are drawn on the basis of Equation (4). It is observed that surface roughness increases with increase in overhang length. Minimum surface roughness (1.135 µm) is found at minimum overhang length (35 mm) and maximum surface roughness (1.383 µm) is found at maximum overhang length (65 mm).

4.5 Optimization of Overhang Length of Tool Holder

The optimized result of the experiment in terms of cutting parameters are shown in the desirability table (Table 8). Desirability is simply a mathematical model to find the optimum results. As there are several factors and responses, all goals get combined into one desirability function.

TABLE 7
DESIRABILITY SELECTION CRITERIA

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:Cutting Speed	is in range	50	100	1	1	3
B:Feed Rate	is in range	0.1	0.2	1	1	3
C:Overhang length	is in range	35	65	1	1	3
Vibration Amplitude	minimize	69.73	75.74	1	1	3
Surface Roughness	minimize	1.135	1.383	1	1	3

In our experiment, the main aim is to minimize the vibration amplitude and surface roughness. So the goals are set according to this.

The Desirability Function Analysis (DFA) takes values in range 0 < d < 1. When the response variable is at its goal or target, d becomes 1, and if the response variable is outside the acceptable range, d becomes zero. In this study, the targets for the responses are minimum value (smaller-the-better).

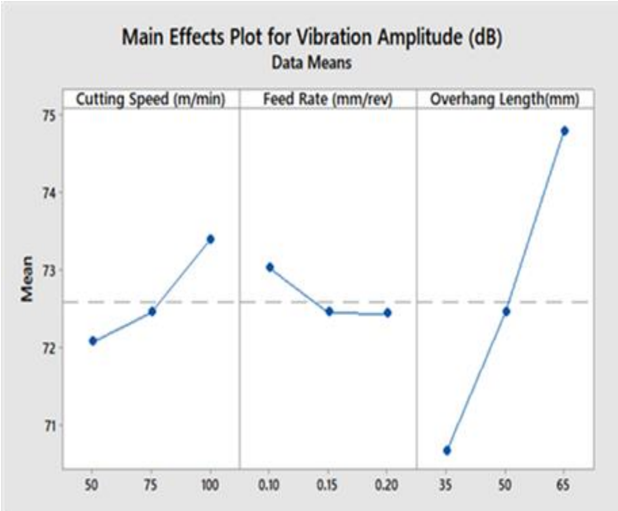
62 solutions have been found from desirability function analysis (DFA). Among them, the desired cutting condition has been attained at shorter overhang length (35 mm) along with lower cutting speed (50 m/min) and higher feed rate (0.200 mm/rev) which gives the minimum vibration amplitude and surface roughness. It can be concluded that shorter overhang length gives the better results than longer overhang length.

TABLE 8
DESIRABILITY FUNCTION ANALYSIS (DFA)

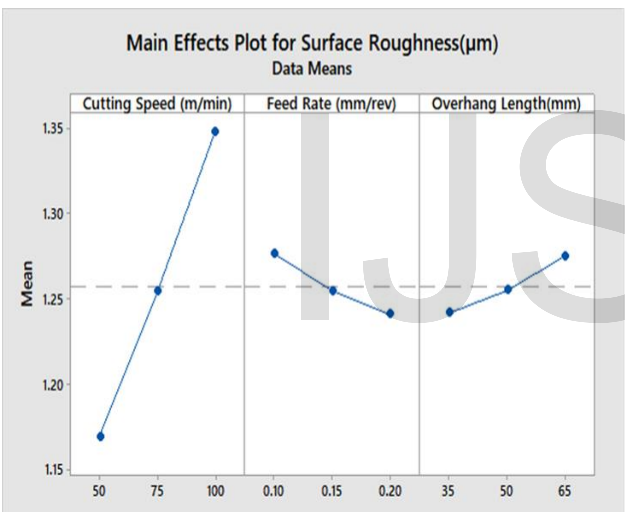
Number	Cutting Speed	Feed Rate	Overhang length	Vibration Amplitude	Surface Roughness	Desirability	
1	**50.000**	**0.200**	**35.000**	**69.779**	**1.136**	**0.995**	Selected
2	50.000	0.199	35.000	69.780	1.136	0.994	
3	50.000	0.199	35.000	69.780	1.136	0.994	
4	50.000	0.198	35.001	69.781	1.136	0.994	
5	50.000	0.200	35.110	69.792	1.136	0.993	
6	50.000	0.197	35.000	69.782	1.136	0.993	
7	50.000	0.196	35.000	69.783	1.137	0.992	
8	50.000	0.200	35.231	69.807	1.136	0.992	
9	50.000	0.196	35.157	69.802	1.137	0.990	
10	50.529	0.200	35.001	69.788	1.137	0.990	

International Journal of Scientific & Engineering Research, Volume 9, Issue 6, June -2018
IISSN 2229-5518

4.6 Main Effects Plot



(a)



(b)

Fig. 4. Main Effects Plot for (a) Vibration Amplitude (b) Surface Roughness

In case of vibration amplitude and surface roughness minimum value is better. From the main effects plot, it is clearly seen that shorter overhang length (35 mm) gives the best result for both responses (Vibration amplitude, surface roughness) along with the lower cutting speed (50 m/min) and higher feed rate (0.20 mm/rev) which is coherent to the results found from 3D plots and Desirability Function Analysis (DFA). According to 3D plots and desirability function minimum surface roughness and vibration amplitude is gained at shorter overhang length (35 mm).

5 Conclusion

The effect of overhang length on output variables such as vibration amplitude and surface roughness in turning operation has been studied by Response Surface Methodology (RSM) and Main Effects Plots. The full factorial design using 20 experiments with varying combinations of machining parameters has been tried. Further, the models for output responses have been developed. Based on these the following conclusions are drawn:

1. R^2 (correlation coefficients) for the quadratic models have been found from Analysis of Variance (ANOVA) which are quite satisfactorily as 0.9652, 0.9820 for vibration amplitude and surface roughness respectively and the P values of the models are less than 0.05 which indicate that the models are significant to 95% level of confidence.

2. From 3-D Response Graphs, it has been clearly observed that overhang length is one of the major causes that affect vibration amplitude and surface roughness. These two responses increase significantly with the increased overhang length. Minimum vibration amplitude (69.73 dB) and surface roughness (1.135 µm) have been found at 35 mm overhang length. And maximum vibration amplitude (75.74 dB) and surface roughness (1.383 µm) have been found at 65 mm overhang length.

3. An optimized result has been found from desirability function analysis (DFA) which indicates that shorter overhang length of the tool holder is preferable to reduce vibration amplitude and get better surface quality. The desired cutting condition has been attained at shorter overhang length (35 mm) along with lower cutting speed (50 m/min) and higher feed rate (0.200 mm/rev) which gives the minimum vibration amplitude and surface roughness.

4. From the main effects plot it has been seen that shorter overhang length (35 mm) gives the best result for both responses (vibration amplitude, surface roughness) along with the lower cutting speed (50 m/min) and higher feed rate (0.20 mm/rev). The results found from main effects plots are coherent to the results found from response surface methodology which gives the experiment a strong validation.

5. Considering all the findings, it can be concluded that 3D response graphs, desirability function, and multi effects plots give almost the similar results and that is minimum length of tool overhangs (35 mm) gives better machining performance in turning AISI 304.

International Journal of Scientific & Engineering Research, Volume 9, Issue 6, June -2018
IISSN 2229-5518

Acknowledgement

Authors wish to acknowledge Department of Mechanical and Production Engineering, AUST for giving permission to use the laboratory facilities.

.References

[1] Abhang LB, Hameedullah M. Optimization of machining parameters in steel turning operation by Taguchi method. Procedia Eng. 2012;38:40–8.

[2] Yuvaraju BAG, Nanda BK. Prediction of vibration amplitude and surface roughness in boring operation by response surface methodology. Mater Today Proc [Internet]. 2018;5(2):6906–15. Available from: https://doi.org/10.1016/j.matpr.2017.11.352

[3] Fleischer J, Schulze V, Klaiber M, Bauer J, Zanger F, Boev N, et al. The Influence of Tool Holder Technologies on Milling Performance. Procedia CIRP. 2016;46:226–9.

[4] Kiyak M, Kaner B, Sahin I, Aldemir B, Cakir O. The dependence of tool overhang on surface quality and tool wear in the turning process. Int J Adv Manuf Technol. 2010;51(5–8):431–8.

[5] Zhao Z, Du Y, Zhang L, Liu B. Tool overhang effect on cutting force in high speed milling. 2010;35(October 2010):616–20.

[6] Khalili K, Danesh M. 27 . Investigation of overhang effect on cutting tool vibration for tool condition monitoring. 2013;171–7.

[7] Bartarya G, Choudhury SK. Effect of cutting parameters on cutting force and surface roughness during finish hard turning aisi52100 grade steel. Procedia CIRP [Internet]. 2012;1(1):651–6. Available from: http://dx.doi.org/10.1016/j.procir.2012.05.016

[8] Suresh R, Basavarajappa S. Effect of Process Parameters on Tool Wear and Surface Roughness during Turning of Hardened Steel with Coated Ceramic Tool. Procedia Mater Sci [Internet]. 2014;5:1450–9. Available from: http://linkinghub.elsevier.com/retrieve/pii/S2211812814008293

[9] Neşeli S, Yaldiz S, Türkeş E. Optimization of tool geometry parameters for turning operations based on the response surface methodology. Meas J Int Meas Confed. 2011;44(3):580–7.

[10] Sahoo P, Pratap A, Bandyopadhyay A. Modeling and optimization of surface roughness and tool vibration in CNC turning of aluminum alloy using hybrid RSM-WPCA methodology. Int J Ind Eng Comput. 2017;8(3):385–98.

Authors

Farhana Dilwar
Department of Mechanical and Production Engineering
Ahsanullah University of Science & Technology
Phone: +880 1521110384
Email: farhanahridi@gmail.com

Rifat Ahasan Siddique
Deparment of Mechanical and Production Engineering
Ahsanullah University of Science & Technology
Phone: +880 1521212698
Email: rifatahasan07@gmail.com