

An Investigation on Influence of Depth of Cut, Feed Rate and Work-Piece Overhang on Induced vibration and Surface Roughness During hard Turning of 41Cr4 Alloy Steel using Response Surface Methodology

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ABSTRACT: An aspect of a set of hard turning experiment conducted on 41Cr4 alloy steel to investigate the influence of the machining, cutting tool and work-piece variables on the machining induced vibration and surface roughness is presented. The response surface methodology, based on central composite design of experiment was adopted. Analysis of the response data was performed in the Design Expert 9 environment. The obtained Quadratic regression models were evaluated for the machining induced vibration and surface roughness as functions of the work-piece overhang, feed rate and depth of cut. The influence of the factors on the response variables were established through analysis of variance. The optimal settings of these factors as are required to minimize the response variables were also determine. It was found that the optimum setting of 80 mm, for the work-piece overhang; 0.15 mm/rev, for the feed rate; and 2.32666 mm, for the depth of cut would minimize the machining induced vibration of the cutting tool to a value of 0.12 mm/s², and the surface roughness of the specimen work-piece to a value of 5.21111 μ mm while keeping other operating factors constant at their intermediate levels within the experimental design space.

KEYWORDS: Depth of Cut, Feed Rate, Work-Piece Overhang, Machining Induced Vibration, Surface Roughness, Central Composite design of Experiment, Response Surface Methodology

I. INTRODUCTION

In machined component manufacture, cylindrical surfaces are generated by turning on either conventional or non-conventional lathe. This is achieved when a translating cutting tool encounters a rotating work-piece under selected machining conditions and other influencing factors. In the past, skills of operators were relied upon to achieve the selection and setting of work materials and tools prior to machining, and hence, the desired quality of product and machining process performance with significant level of inconsistency due to human factors. This has given rise to failure of machined parts while in service, reduced market value of products, and numerous other consequences to mention but few. In recent times, the drive towards application of modern techniques of experimental design, data analysis and optimization, as attempt to reduce dependence on human skill, is gaining strength and flavour through research and development. Some of these efforts have been reviewed in the works of Aggarwal and Singh [1], which concludes that the latest techniques of optimization include fuzzy-logic, scatter search technique, genetic algorithm, Taguchi technique, and response surface methodology; and in the works of Kumar and Uppal [2], which concludes that Taguchi technique is the most widely used in optimizing the turning operation. The complex nature of turning process requires that application of these techniques be thoroughly investigated so that adequate information would be available to the end user, hence the numerous efforts so far and those yet to be provided.

The study undertaken, in which a series of hard turning experiments were conducted to investigate the dependence of the machining induced vibration and surface roughness on the machining, cutting tool and work-piece variables, was

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supported by the works of Ozcakar and Kasapoglu [3], Abhang and Hameedullah [4], Sahoo [5], Abhang and Hameedullah [6], Sastry and Devi [7], Srinivasan et al [8], Ramudu and Sastry [9], Aruna and Dhanalaksmi [10], Chomsamutr and Jongprasithporn [11], Abhang and Hameedullah [12], Manu et al [13], Makadia and Nanavati [14], Kannan et al [15], Phate and Tatwawadi [16], Bhuiyan and Ahmed [17], Manohar et al [18], Thiyaagu et al [19], Saini and Parkash [20], Saini et al [21], Soni et al [22], Shunmugesh et al [23], Kumar [24], Sastry et al [25], Revankar et al [26], Mahajan et al [27], Shihab et al [28], and Gupta and Kohli [29], Khan et al [30], Devkumar et al [31], Devi et al [32], Rajpoot et al [33], Khidhir et al [34], Agrawal et al [35], Ranganath et al [36], and Chandra and Prasad [37]. The response surface methodology (RSM), as used in these works, was based on a variety of approach on design of experiment, and the generated data analyze in a variety of software environment. A variety of work-piece materials, cutting tools, lathe machines, and parameter measurement instruments were considered. A variety of process variables and constants, and performance variables were investigated. However, results obtained from surface roughness data are in close semblance. Besides, the study is supported by the work of Kassab and Khoshnaw [38], Han et al [39], Cahuc et al [40], Delijaicov et al [41], Rogov and siamak [42], [43], which consider essentially the machining induced vibration as of either the cutting tool or work-piece as the response variable.

The same response surface methodology (RSM) of the above mentioned works, though based on central composite (CC) design of experiment (DOE), is used in this work to model, predict and optimize the machining induced vibration (V_i) and surface roughness (R_a) as functions of the work-piece overhang (A), feed rate (B), and depth of cut (B) during hard turning of 41Cr4 alloy structural steel on a conventional lathe with a standard cutting tool and devices for measurement of the machining induced vibration and surface roughness. Analyses of the machining induced vibration and surface roughness data are performed in the Design Expert 9.0.6.2 environment.

II. MATERIAL, EQUIPMENT AND METHOD

Work-Piece Material. To establish the chemical composition and mechanical properties of sample of the selected work-piece material, it was subjected chemical analysis and mechanical tests. These were performed at Standards organization of Nigeria, Emene, Enugu, with standard facilities. Tables I and II gives the outcome of the tests, which revealed work-piece material to be 41Cr4 quenched and tempered (QT) alloy special steel, with material number as 1.7035. Equivalent grades of this material are SAE-AISI 5140, BS 530M40, EN 10083-3 or EN18, and VC140. They have no semblance with those previously investigated. Technical report by FUHONG on special steels claims 41Cr4 to be one of the most widely used alloy steel. In the same report, 41Cr4 is recommended for driving elements like crankshafts, front vehicle axles, axle journals and steering components. 41Cr4 alloy steel is also seen as having good overall mechanical properties, low temperature impact toughness and hardenability after quenching and tempering (QT) heat treatment; and higher fatigue strength after oil cooling. The machinability of this material is good when subjected to normalizing and QT conditions, but its weldability is not good, and as a result, cannot easily be produced when subjected to welding conditions. For the turning experiment, specimen work-piece of this material, given in Fig. 1, are round bars having dimensions of diameter, 25 mm, and length, 150 mm.



Figure 1. Samples of 41Cr4 Alloy Steel Bars

Table I
CHEMICAL COMPOSITION OF 41CR4 ALLOY SPECIAL STEEL

Quality of material	Type of material	Average elements %			
		Carbon (C)	Silicon (Si)	Manganese (Mn)	Chromium (Cr)
Quenched and Tempered Steel	41Cr4	0.40	0.25	0.65	1.00

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Table II
MECHANICAL PROPERTIES OF 41CR4 ALLOY SPECIAL STEEL

Sample ID	Diameter (mm)	Area (mm ²)	BHN	Peak load (kN)	U _s N/mm ²
Solid, Round	10.00	78.55	278.48	70.92	902.83

Processing Equipment. The experiment was conducted by turning the selected material on a conventional lathe machine, that is, YUCY6240B Engine Lathe, with serial number: 2008031074, such as given in Fig. 2a, with a carbide cutting tool of the type F30, such as given in Fig. 2b. The overall dimensions of the tool insert is 25 mm x 25 mm x 12.5 mm. Its back rake angle is 10°, side rake angle is 12°, side relief angle is 5° and side cutting edge angle is 15°.

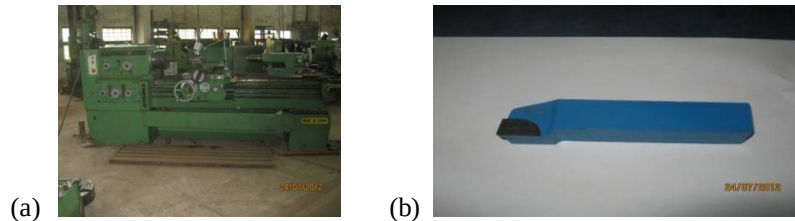


Figure 2. (a) Conventional Lathe Machine; (b) Cutting Tool with Carbide Insert, F30

Input Variables. A set of input/process variables selection made from the machining, cutting tool and work-piece variables include work-piece overhang (A), feed rate (B) and depth of cut (C), with others kept constant within experimental limits. Work-piece overhang (A) is the length of work-piece disposed for machining. It is measured in mm. Feed rate (B) is the speed of the cutting tool relative to that of the work-piece as the tool takes a cut along the axis of the work-piece [2]. It is measured in mm per revolution. The depth of cut (C) is taken along the radius of the work-piece as the tool cuts into it in a turning operation [2]. It is measured in mm. The extent to which these variables influence the surface roughness (R_a) and machining induced vibration (V_i), is being investigated. To improve on quality of the machined part, variables A, B and C can be set within limits (Table III) as to minimize R_a and V_i .

Table III
LEVELS OF THE INPUT VARIABLES

S/N	Parameters	Notation	Unit	Levels		
				Low	Medium	High
1	Work-piece Overhang	A	[mm]	80	100	120
2	Feed rate	B	[mm/rev]	0.15	0.20	0.30
3	Depth of cut	C	[mm]	50	55	60

Output Variables. A set of output/performance variables selection amongst others include surface roughness (R_a) and machining induced vibration (V_i). In the first instance, R_a has been shown to be a measure of surface texture [2]. It has been found to be the vertical deviations of a real surface from its ideal form, with a large deviation taken as a rough surface, and a small deviation as a smooth surface. Roughness of a surface, therefore, is seen as the high frequency, short wavelength component of a measured surface. It determines how a real object will interact with its environment. For instance, rough surfaces wear faster and have higher coefficient of friction than smooth surfaces. Also, roughness of a surface may form nucleation sites for cracks or corrosion, promote adhesion, and may be very expensive to control in manufacturing. It is measured in microns, micro-meters or micro-millimeters. In this study, measurements of the surface roughness were undertaken using an inside surface roughness tester, ISR-16, such as given in Fig. 3a. They were taken at three different positions located at 120° on the surface and about the axis of the work-pieces. The surface texture of the turned surface is taken to be the average of these values. As reported in [5], R_a [μm] is the center line average roughness, also known as, the arithmetic deviation of the surface height from the mean line through the profile, which separates the profile above and below it by equal area.

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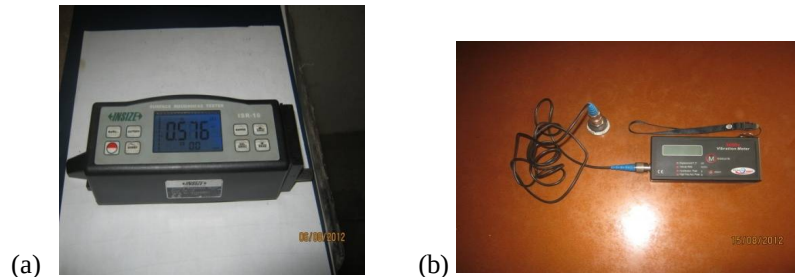


Figure 3. (a) Surface Roughness Tester, ISR-16; (b) Vibration Meter with Transducer, 908 BE

Vibrations may occur, during turning and allied lathe operations, due to (a) sudden clash of a tool against a work-piece, (b) irregular tissues of the work-piece, (c) regular excitation due to asymmetric torque, and (d) due to bearing defects. A sudden clash of a tool against a work-piece, self-excited vibration, or machining induced vibration occurs at the cutting zone due to interaction of the cutting tool, chips, and the work-piece. If it is excessive, it is known as chatter [38], [39], [40]. Effects of chatter include (a) defective machined surface, and (b) excessive wear and breakage of the cutting tool. Its influence on the surface roughness of machined components is significant [41], [42], [43]. Machining induced vibration cannot be manipulated or controlled, but can be measured, and therefore, is treated as a response variable, measured as an acceleration amplitude in m/s^2 , using a vibration meter with transducer, type 908 BE, such as given in Fig. 3b. A vertical data of a transducer mounted near to the tip and connected to the vibration meter, was used to measure the level of tool vibration. The data for each sample included amplitude of displacement and velocity of the point on the cutting tool. The acceleration, thereafter, was calculated from the relation between the displacement, velocity and acceleration.

Design of Experiment and Analysis of Data. Most techniques of design of experiment attempt to minimize the number of runs or trials, optimize values of parameters, assess experimental error, make qualitative estimation of parameters, and to make inference regarding the effect of parameters on the characteristics of the process [1]. For this reasons, the response surface methodology (RSM), based on central composite (CC) design of experiment (DOE), was selected. RSM, therefore is use in this work to model, predict and optimize R_a and V_i as functions of A, B and C. It is a mathematical and statistical technique developed for treatment of problems involving a response of interest as a function of several variables [5]. It is one of the ways machining process modeling and analysis can be achieved to facilitate its optimization. Its application requires machining response Y to be defined as: $Y = \phi(x_1, x_2, \dots, x_i) \pm e$, where $\phi(x_1, x_2, \dots, x_i)$ is the response surface function in the form of a polynomial model, x_i are the process variables and e is the residual or experimental error. The second order polynomial or quadratic model may, therefore, be written as:

$$\phi = \phi(x_1, x_2, \dots, x_k) = (Y \pm e) = b_0 + \sum_{i=1}^k b_i x_i + \sum_{i=1}^k b_{ii} x_i^2 + \sum_{i=1}^k b_{ij} x_i x_j \quad (1)$$

The multiple regression model (Eq. 1) of this form has constant, linear, square and cross-product terms. It can satisfactorily be used to correlate dependent variables, ϕ_j , with independent variables, x_i . A number techniques for design of experiment (DOE) are available for use to estimate the coefficients of the regression models. The central composite (CC) was selected for the design of the turning experiment. Analysis of variance (ANOVA) was used to validate the developed models, and also, to predict the effect of selected factors A, B and C on the response characteristics, V_i and R_a . Optimization of the response functions, $V_i(A, B, C)$ and $R_a(A, B, C)$, subject to constraints as determined by the limits of the factors A, B and C, was performed as appropriate using standard optimization technique. The RSM was implemented in the Design Expert 9 software version 9.0 6.2 environment.

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Experimental Procedure. The setup for the turning experiment is shown in Fig. IV. Twenty-seven (27) specimen work-piece of 41Cr4 alloy steel round bars (Fig. 1) were turned on the conventional lathe (Fig. 2a) with carbide tool insert (Fig. 2b). The sequence is as generated from Design Expert 9 software based on CC-DOEas given in Table 4. Measurements of V_i data were taken three times with a vibration transducer (Fig. 3b) placed on the tool post near the cutting zone. The data was transmitted to the vibration meter (Fig. 3b), and read out as displacement and velocity. The average cutting tool acceleration was determined from the general relations between displacement, velocity and acceleration. Again, measurements of R_a data were taken at three (3) different locations, 120° from each other, on the machined surface using a surface roughness tester (Fig. 3a) and the average values were recorded.

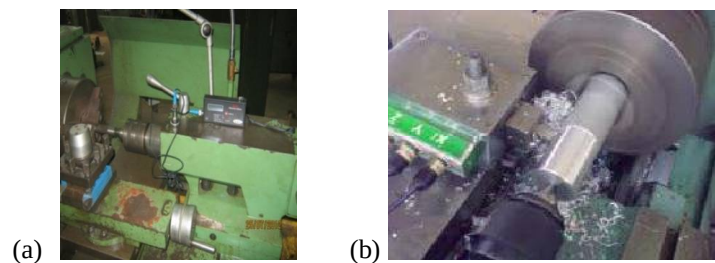


Figure 4. Setup for the Turning Experiment

III. RESULTS AND DISCUSSION

The turning experiments were conducted under a controlled environment to minimize error. Data generated were recorded as shown in Table IV. Results of data analysis in the environment of the Design Expert software, version 9.0.6.2, are presented and discussed as follows:

Table IV
DATA GENERATED FROM THE TURNING EXPERIMENT

Standard	Run	A Work-Piece Overhang [mm]	B Feed Rate [mm per Rev]	C Depth of Cut [mm]	V_i Acceleration Amplitude [mm per min square]	R_a Surface Roughness [micro mm]
1	7	80	0.15	1	0.26	5.436
2	22	100	0.15	1	0.25	7.259
3	1	120	0.15	1	0.24	6.53
4	26	80	0.225	1	0.28	6.425
5	23	100	0.225	1	0.29	6.629
6	6	120	0.225	1	0.25	8.435
7	11	80	0.3	1	0.41	10.11
8	3	100	0.3	1	0.36	10.01
9	13	120	0.3	1	0.29	9.345
10	5	80	0.15	2	0.13	5.579
11	19	100	0.15	2	0.14	5.209
12	17	120	0.15	2	0.16	5.867
13	2	80	0.225	2	0.17	6.546
14	10	100	0.225	2	0.15	7.381
15	27	120	0.225	2	0.12	9.412
16	16	80	0.3	2	0.25	8.92
17	12	100	0.3	2	0.22	9.66
18	9	120	0.3	2	0.21	8.442

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19	15	80	0.15	3	0.23	5.613
20	20	100	0.15	3	0.24	5.35
21	18	120	0.15	3	0.29	5.237
22	14	80	0.225	3	0.26	6.112
23	8	100	0.225	3	0.27	6.895
24	21	120	0.225	3	0.34	7.034
25	24	80	0.3	3	0.39	7.815
26	4	100	0.3	3	0.41	8.319
27	25	120	0.3	3	0.40	8.421

Machining Induced Vibration Data. The model summary statistics, as given Table V, suggests a quadratic model. As suggested, the model accuracy is predicted by the standard deviation of 0.019 and PRESS of 0.014, and also, by the adjusted R-square of 0.9519 and predicted R-square of 0.9268. It is not aliased, and has significant terms. The ANOVA of Table VI confirms the significance of the model, and its capability for accurate prediction of V_i within the selected limits. The significant model terms as predicted are only B, C, B^2 , C^2 , AB and AC. These are the only good predictors of V_i . For the linear terms, B has dominant influence on V_i followed by C, and then, A. For the square terms, C^2 has dominant influence on V_i followed by B^2 , and then A^2 . For cross-products terms, AC has dominant influence on V_i followed by AB, and then, BC. As shown in Table VII, the predicted R-square of 0.9268 is found to be in reasonable agreement with the adjusted R-square of 0.9519 since the difference of 0.0251 is less than 0.2. The adequacy precision of 24.97, greater than 4, is a desirable signal to noise ratio. This indicates that there is adequate signal, and that this model can be used to navigate the design space. The models for the machining induced vibration (V_i), given in terms of the coded and actual factors A, B and C, respectively, are as follows:

$$V_i = 0.15 - 0.0044A + 0.056B + 0.011C - 0.018AB + 0.027AC + 0.011BC + 0.0011A^2 + 0.034B^2 + 0.13C^2 \quad (2)$$

$$V_i = 0.9007 - 0.0007A - 1.0815B - 0.6792C - 0.0122AB + 0.0013AC + 0.1444BC + 0.000003A^2 + 6.1235B^2 + 0.1311C^2 \quad (3)$$

Table V MODEL SUMMARY STATISTICS						
Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	0.075	0.3087	0.2186	0.0682	0.18	
2FI	0.076	0.3830	0.1978	-0.1106	0.21	
Quadratic	0.019	0.9686	0.9519	0.9268	0.014	Suggested
Cubic	0.016	0.9861	0.9637	0.8915	0.020	Aliased

Table VI ANOVA FOR RESPONSE SURFACE QUADRATIC MODEL FOR ACCELERATION AMPLITUDE (V_i)						
Source	Sum of Squares	Degree of freedom	Mean Square	F Value	p-value Prob > F	
Model	0.18	9	0.020	58.18	< 0.0001	significant
A-Work-Piece Overhang	3.556E-004	1	3.556E-004	1.02	0.3265	
B-Feed Rate	0.056	1	0.056	159.50	< 0.0001	
C-Depth of Cut	2.222E-003	1	2.222E-003	6.38	0.0218	
AB	4.033E-003	1	4.033E-003	11.58	0.0034	

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AC	8.533E-003	1	8.533E-003	24.50	0.0001	
BC	1.408E-003	1	1.408E-003	4.04	0.0605	
A^2	7.407E-006	1	7.407E-006	0.021	0.8858	
B^2	7.119E-003	1	7.119E-003	20.44	0.0003	
C^2	0.10	1	0.10	296.12	< 0.0001	
Residual	5.921E-003	17	3.483E-004			
Cor Total	0.19	26				

Table VII QUADRATIC MODEL STATISTICS			
Standard. Dev.	0.019	R-Squared	0.9686
Mean	0.26	Adjusted R-Squared	0.9519
C.V. %	7.19	Predicted R-Squared	0.9268
PRESS	0.014	Adequacy Precision	24.970

Figure 5a illustrates how well the predicted V_i data fits the actual data. Figure 5b reveals the predicted V_i to have linear relationship with factor A and nonlinear relationship with factors B and C. The significance of the effect of B and C on V_i is much more both at the lower and higher levels of these factors, when compared to that of A. V_i slightly decreased with increase in A, but increased with increase in B. It decrease with increase in C to the reference point, and then, increased from the same point. The implication of the behavior is that V_i is minimized when the factors A is set at higher level of its values and B set at lower level of its values, while factor C is set at the reference point. These behaviors can also be seen in the contour and response surface plots given in Figs 6 to 8. It can as well be attributed to the observed interaction between factors.

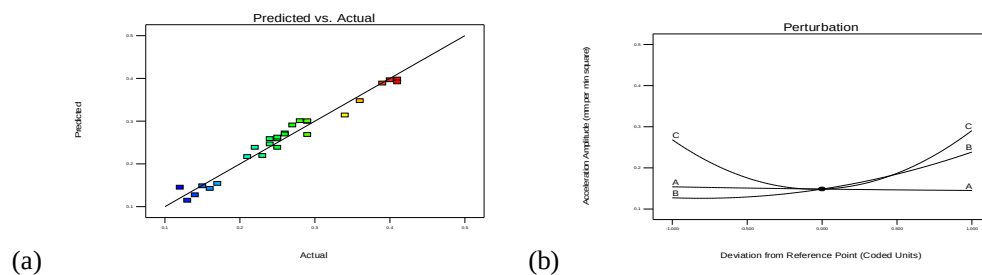


Figure 5: (a) A Plot of the Predicted V_i against the Actual values; (b) A Plot of V_i against the deviation from reference point (Coded Unit) or perturbation

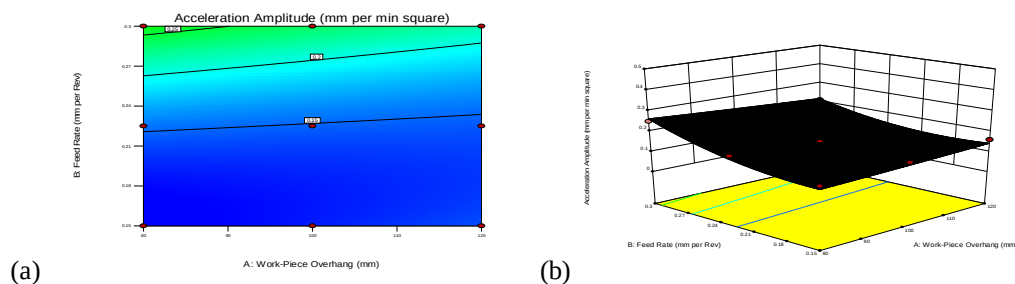


Figure 6: (a) A Contour plot of V_i against A and B with C set at 2 mm; (b) A Response Surface plot of V_i against A and B with C set at 2 mm

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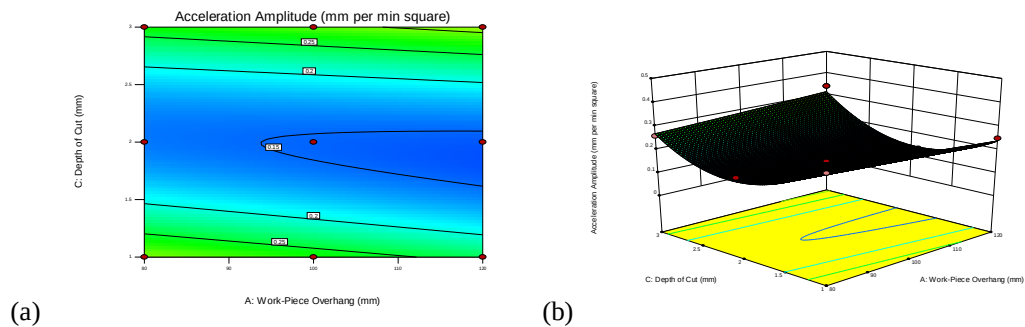


Figure 7: (a) A Contour plot of V_i against A and C with B set at 0.225 mm/rev; (b) A Response Surface plot of V_i against A and C with B set at 0.225 mm/rev

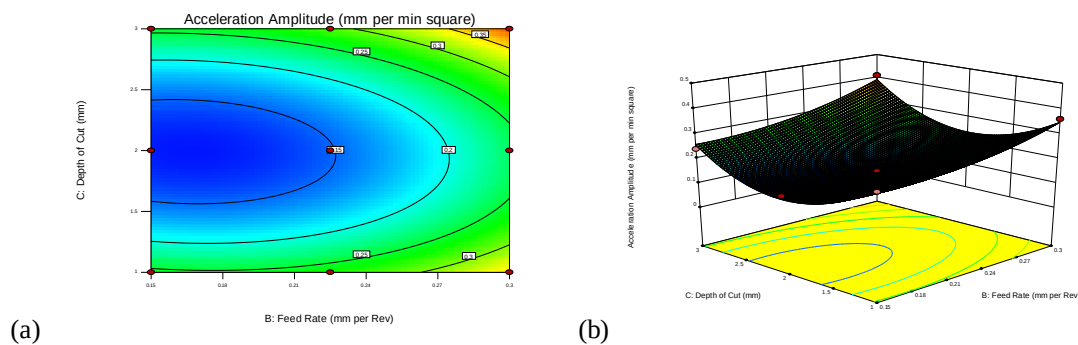


Figure 8: (a) A Contour plot of V_i against B and C with A set at 100 mm; (b) A Response Surface plot of V_i against B and C with A set at 100 mm

Surface Roughness Data. Table VIII is the model summary statistics for the surface roughness data. It shows a linear regression model is adequate and accurate fit for the surface roughness data. It recorded a standard deviation of 0.70, R-square value of 0.8247, adjusted R-square value of 0.8018, and predicted R-square value of 0.7654. Table IX is analysis of variance (ANOVA). It shows the model is significant for accurate prediction of the surface roughness R_q within the design limits of factors A, B and C. It also shows only linear the model terms, B and C to be significant, with B having dominant influence on R_q followed by C, and then, A. Table X is the quadratic model statistics. It reveals the predicted R-square value of 0.7654 to be in reasonable agreement with the adjusted R-square value of 0.8018, since the difference of 0.0364 is less than 0.2. The adequacy precision of 18.256, greater than 4, is a desirable signal to noise ratio. This indicates that there is adequate signal, and that this model can also be used to navigate the design space. The models for the surface roughness (R_q), given in terms of the coded and actual factors A, B and C are as follows:

$$R_q = 7.33 + 0.34A + 1.61B - 0.52C \quad (4)$$

$$R_q = 1.83550 + 0.017131A + 21.45333B - 0.52128C \quad (5)$$

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Table VIII MODEL SUMMARY STATISTICS						
Source	Standard. Deviation.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	0.70	0.8247	0.8018	0.7654	15.25	Suggested
2FI	0.73	0.8345	0.7849	0.7153	18.50	
Quadratic	0.78	0.8418	0.7580	0.6252	24.36	
Cubic	0.69	0.9266	0.8092	0.4995	32.53	Aliased

Table IX ANOVA FOR RESPONSE SURFACE LINEAR MODEL FOR SURFACE ROUGHNESS (R_a)						
Source	Sum of Squares	Degree of Freedom	Mean Square	F Value	p-value Prob > F	
Model	53.60	3	17.87	36.07	< 0.0001	significant
A-Work-Piece Overhang	2.11	1	2.11	4.26	0.0504	
B-Feed Rate	46.60	1	46.60	94.06	< 0.0001	
C-Depth of Cut	4.89	1	4.89	9.87	0.0046	
Residual	11.39	23	0.50			
Cor Total	65.00	26				

Table X LINEAR MODEL STATISTICS			
Standard. Deviation.	0.70	R-Squared	0.8247
Mean	7.33	Adjusted R-Squared	0.8018
C.V. %	9.60	Predicted R-Squared	0.7654
PRESS	15.25	Adequacy Precision	18.256

Figure 9a is a plot of the predicted values of R_a (Eq. 6) against its actual values (Table 4). It shows how well the predicted R_a data fits the actual data. Fig 9b shows R_a to have linear relationship with A, B and C. It shows the influence of factors B and C on R_a to equally be highly significant compared to that of A. It is important to note that R_a increased with increase in A and B, but decreased with increase in C. These behaviors have implication of R_a being minimized when the factors A and B are set at the extremelower level of their values, and the factor C set at the extreme high level of its value. They can also be seen in the contour and response surface plots given in Figs 10 to 12. They can be attributed to the observed none interactions of factors.

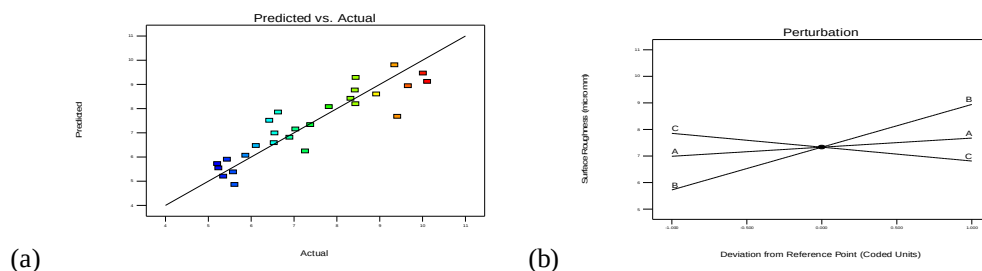


Figure 9: (a) A Plot of the Predicted R_a against the Actual values; (b) A Plot of R_a against the deviation from reference point (Coded Unit) or perturbation

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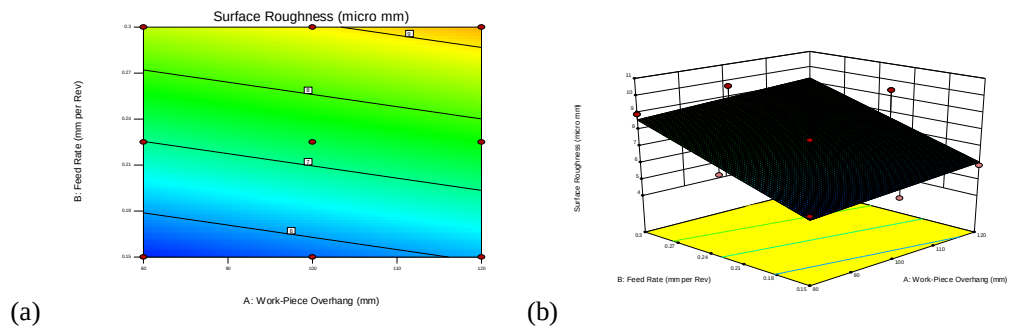


Figure 10: (a) A Contour plot of R_a against A and B with C set at 2 mm; (b) A Response Surface plot of R_a against A and B with C set at 2 mm

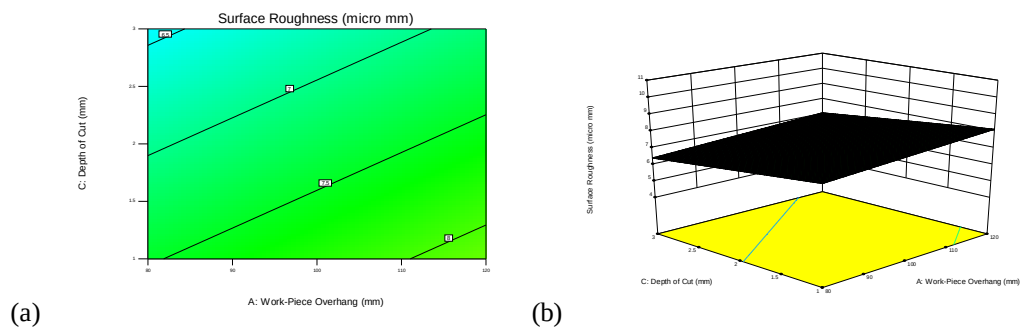


Figure 11: (a) A Contour plot of R_a against A and C with B set at 0.225 mm/rev; (b) A Response Surface plot of R_a against A and C with B set at 0.225 mm/rev

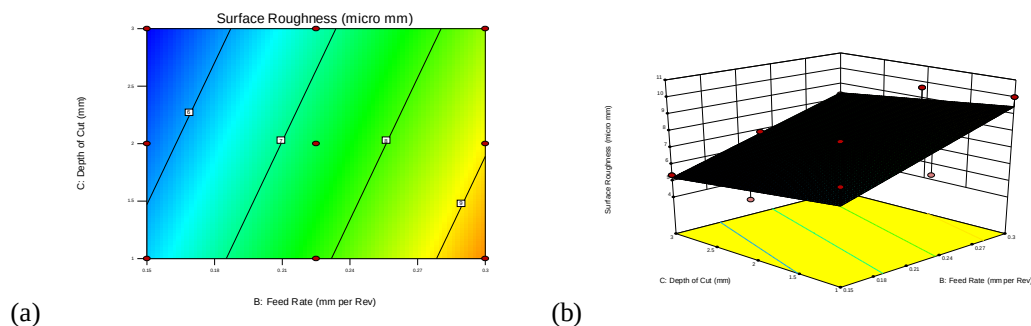


Figure 12: (a) A Contour plot of R_a against B and C with A set at 1 mm; (b) A Response Surface plot of R_a against B and C with A set at 100 mm

Parameter Optimization. The quality of a machined surface is a function of its roughness, which in turn depend the level of induced vibration. Being undesirable as well as uncontrollable, the two process characteristics, that is the machining induced vibration (V_i) of the cutting tool, and the surface roughness (R_a) of the specimen work-piece, must be minimized to improve on product quality. Both were measured using standard instruments in the turning experiment. As given in the ramps of Fig 23, the optimum setting of the factors, A at 80 mm, B at 0.15 mm/rev, and the factor C at 2.32668 mm, would minimize V_i to a value of 0.12 mm/s² and R_a to a value of 5.21111 μ mm with desirability of 1.0,

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which occurred within the selected design space. As shown in Fig 13 and confirmed by the contour and surface plots of Figs 6 to 8 and Figs 10 to 12, V_i and R_a are both minimized at low values of A and B, and higher value C.

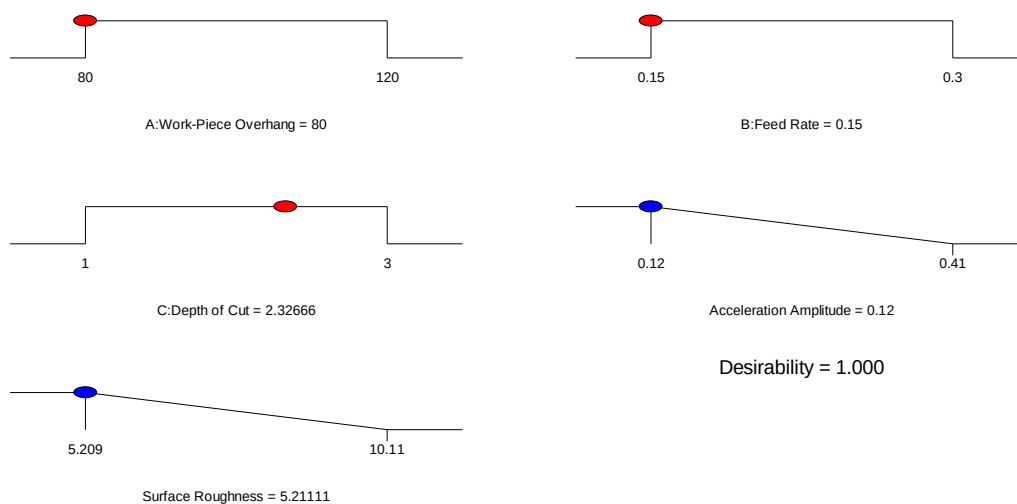


Figure 13: Optimum Setting of the Process Variables, which Minimized the Surface Roughness and Machining Induced Vibration

Surface Roughness VS Machining Induced Vibration. If excessive, the machining induced vibration (V_i) should have influence on surface roughness (R_a) as it impacts negatively on the cutting zone in a turning operations. However, the plot of R_a versus V_i given in Fig 14, shows a nonlinear relationship, but no significant correlation between these process characteristics within the experimental design limits. This can be seen from the R-square value of the trend line of 0.1982, but there may be correlation outside these limits.

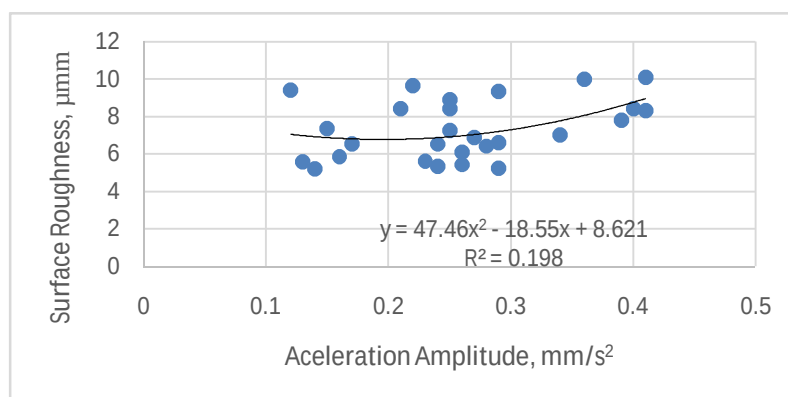


Figure 14: A plot of R_a against V_i

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IV. CONCLUSION

The work used response surface methodology, based on the central composite design of experiment to model, predict and optimize the machining induced vibration of the cutting tool and surface roughness of the work-piece as functions of the work-piece overhang, feed rate and depth of cut. In an experiment conducted, 41Cr4 alloy special steel was turned on a conventional lathe with standard cutting tool and response parameters measuring instruments. Analyses and optimization of the response characteristics data was performed in the Design Expert version 9.0.6.2 software environment. It was found that:

- Within limits of the selected factors, the developed regression models can be used for accurate prediction of the selected process and quality characteristics.
- A nonlinear relationship was found to exist amongst the machining induced vibration of the cutting tool, and the feed rate and depth of cut. Whereas a linear relationship exist between the machining induces vibration and work-piece overhang. The effect of the feed rate and depth of cut on the machining induced vibration is significant when compared to effect of work-piece overhang. The machining induced vibration would be minimized when the feed rate is set at its extreme low value, work-piece overhang is set at it extreme high value, and the depth of cut is set at its intermediate value.
- A linear relationship was found to exist between the surface roughness of the work-piece and the work-piece overhang, feed rate and depth of cut. The effect of the feed rate and depth of cut on the surface roughness is much more significant when compare to that of work-piece overhang. The surface roughness is minimized when the work-piece overhang and feed rate are set at their extreme low value, and the depth of cut set at its extreme high value.
- Within the selected design space, the optimum setting of the work-piece overhang at 80 mm, feed rate at 0.15 mm/rev, and depth of cut at 2.32668 mm, would minimize V_i to a value of 0.12 mm/s² and R_a to a value of 5.21111 μ mm with desirability of 1.0.

Within the selected design space, there is a nonlinear relationship, and no significant correlation between the surface roughness and the machining induced vibration. This is suggested by the R-square value of 0.1982. However, there may be correlation outside this limits.

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