Research Paper

PREDICTION OF CUTTING TOOL VIBRATION IN HARD TURNING USING RESPONSE SURFACE METHODOLOGY

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ABSTRACT

In this experimental work, the prediction models have been developed to predict acceleration amplitude tool vibration in hard turning. The material used for this experiment is austempered ductile iron grade 3. On-line acceleration amplitude of tool vibration in main cutting force and radial cutting force are measured. The cutting parameters are the depth of cut, feed rate and cutting speed in three levels. The experiments are conducted as per Taguchi L_9 orthogonal array. ANOVA is used to calculate significant factors affecting the tool vibration amplitude. Linear square regression is used to estimate the acceleration amplitude of tool vibration main cutting force and radial cutting force. Based on the ANOVA result, it found that cutting speed and depth of cut are the most dominant factor affecting the acceleration of tool vibration in main cutting force and radial cutting force respectively. The developed regression model was verified by confirmation experiment. The estimated and experimental values for acceleration amplitude of tool vibration in main and radial cutting force adhere very much to 14.5 % and 15 % of maximum deviations respectively.

KEYWORDS: Tool vibration; hard turning; Austempered ductile iron; Response surface Methodology.

1. INTRODUCTION AND LITERATURE REVIEW

The decreased acceleration amplitude of tool vibration in machining process produces the good surface finish and reduces the tool wear. Therefore the prediction of acceleration amplitude of tool vibration is very important and increases the quality of machined part. Hence the tool monitoring is needed to predict the tool vibration [1]. In machining the surface finish of the finished product is used as index of finished part [2]. Therefore the tool vibration prediction is the important to achieve a desired quality and minimum tool wear. The researchers' extensively used response surface methodology, artificial Neural Networks, fuzzy nets and genetic algorithm in prediction of tool vibration.

The following literature shows many researchers used various methods to predict the tool vibration. P. S.Sivasakthivel et al. [1] developed a prediction model using response surface methodology for vibration amplitude prediction in end milling process. The amplitude of vibration was measured in the feed direction and axial cutting direction. They found that higher feed rate produces the minimum tool vibration. In another work, Kuldip Singh Sangwan et al. [3] used integrated ANN and GA for prediction of surface roughness in turning of Ti-6Al-4V titanium alloy. They found that feed rate was a most dominant factor affecting surface roughness and mean error percentage was calculated as 1.79. Gabriel Medrado Assis Acayaba and Patricia Mun˜oz de Escalona [4] used Multiple Linear Regression (MLR) and artificial neural network for prediction of surface roughness in turning of austenitic stainless steel at low cutting speed. The artificial neural network developed better prediction than the linear regression, based on the result. In another experimental work, R. Kumar and S. Chauhan [5] used RSM and ANN in the prediction of surface roughness in turning of the hard composite using the polycrystalline diamond tool. Based on experimental results, the feed rate was a most dominant factor affecting the surface roughness and found that RSM prediction accuracy better than ANN prediction. A.K. Ghani et al. [6] studied the effect of cutting parameters on tool vibration. The tool vibration was measured in main cutting force and radial cutting force direction. The result indicated that magnitude of tool vibration in the main cutting force higher than radial cutting force. The increase in cutting speed and depth of cut increases tool vibration and tool wear.

The many researchers have used tool vibration and cutting parameters in the prediction of surface roughness and tool wear. Vikas Upadhyay et al. [7] developed the prediction model for turning of Ti–6Al–4V alloy using regression analysis. The acceleration amplitude of tool vibration and cutting parameters were used for prediction of surface roughness. Based on experimental results, higher accuracy in the prediction was achieved after considering the tool vibration. In another work, S. S. Abuthakeer et al. [8] studied the effect of spindle vibration on surface roughness. They used ANN for prediction of tool vibration and surface roughness. The results were efficiently predicted by ANN for surface roughness and spindle vibration prediction. M. Elangovan et al. [9] used vibration signals for the prediction of surface roughness using regression analysis in turning. The prediction results produced with higher predictability**.** K. Venkata Rao et al. [10] used work piece vibration; cutting parameter and nose radius for prediction of surface roughness and tool wear in internal boring using Taguchi and regression. Higher tool wear observed with higher vibration amplitude.

The minimum acceleration amplitude of tool vibration produces a better quality surface finish and minimum tool wear. Hence the tool vibration predictions need to develop. In this experimental work, the acceleration amplitude of the tool vibration prediction model developed using cutting parameters such as depth of cut, feed rate and cutting speed. The liner square regression model was used to predict the acceleration amplitude tool vibration in main cutting force and radial cutting force. The confirmation experiment was conducted to check the developed model's reliability. A regression model was successfully used in prediction tool vibration.

2. EXPERIMENTAL DETAILS

The material used in this experimental work was austempered ductile iron grade 3. The chemical composition of the austempered ductile iron is C-3.42 %, Si-2.47 %, Mn-0.415 %, Cu-0.458 %, Cr-0.027 %, P-0.029 %, S-0.005 %, Mg-0.020 %, Sn-0.079 %. The size of the work piece was 35 mm diameter and 90 mm length. The work material was austenitized for 2 hrs at 880^o C and then quenched in a 50% $NaNO_3$+50%KNO_3 salt bath for 2 hrs at 230^{o}C. The following mechanical properties were obtained after heat treatment Tensile Strength: 1241 Mpa, Hardness: 341BHN and % of Elongation: 4.88

The machining was carried out in CNC (Galaxy Midas 6) machine under dry cutting condition. The carbide insert used for this experimental work was CNMG120408 RT. The inset manufacturer is TaeguTec and the code is TT7310. A new cutting edge was used for every experiment. The insert was rigidly fixed on PCLNR2020K12 RH. The work material was turned for 1 mm depth to avoid irregularities before turning. The ranges and levels of cutting parameter as shown in Table.1 The acceleration amplitude of tool vibration in main cutting force and radial cutting force was measured using two accelerometers made by Kistler. The accelerometer signals were sent to NI 9234 C-DAQ. The lab view software was used to process the signals. The vibration measurement, experimental setup for turning of austempered ductile iron shown in Fig.1

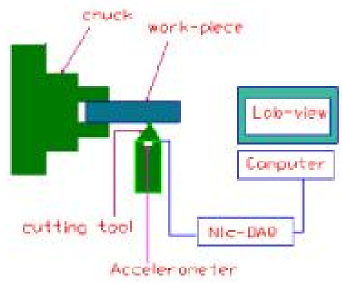


Fig.1 The experimental setup for tool vibration measurement

Table.1 Cutting parameters and their levels for Turning

Symbol	Cutting parameter	Unit	Level 1	Level 2	Level 3
V	Cutting speed	m/min	50	100	150
f	Feed rate	mm/rev	0.04	0.08	0.12
d	Depth of cut	mm	0.2	0.3	0.4

3. EXPERIMENTAL DESIGN

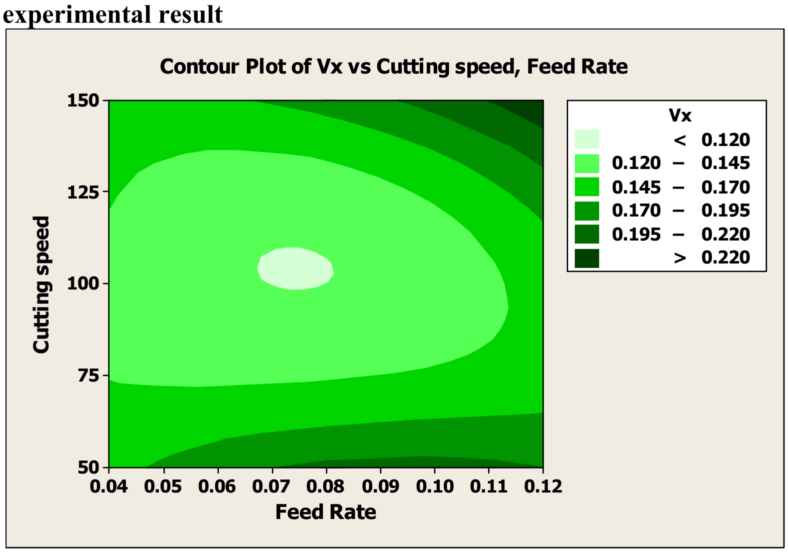
The experiment conducted as per Taguchi L_9 orthogonal array. The orthogonal array is used to reduce no of experiment trails. The ranges of cutting parameter selected based on the cutting tool manufacturer recommendation (TaeguTec) and literature survey. The experimental design involves variation of cutting parameters in three levels. The experiments conducted as per Taguchi L_9 orthogonal array and results are shown in Table.2

Table. 2 The L_9 orthogonal array and experimental result

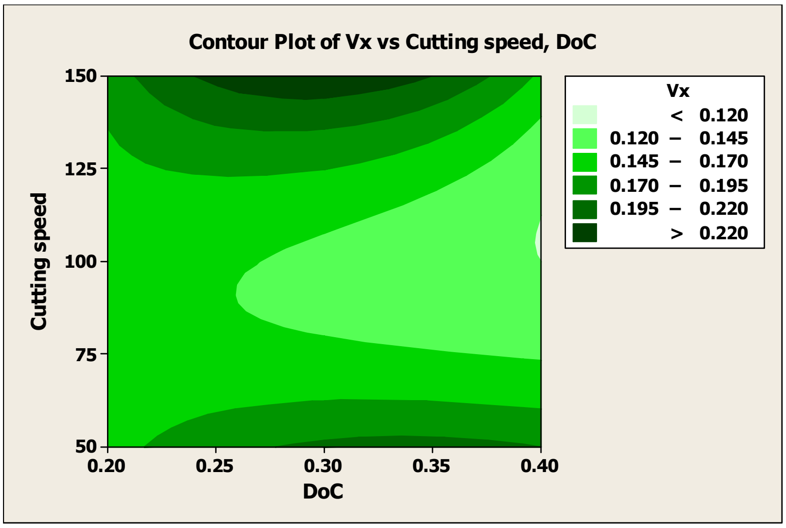
S.N	Cutting speed	Feed Rate	Depth of cut	Cutting speed (m/min)	Feed Rate (mm/rev)	Depth of cut (mm)	Vibration in main cutting force (Vx)	Vibration in radial cutting force(Vy)
1	1	1	1	50	0.04	0.2	0.16	0.052
2	1	2	2	50	0.08	0.3	0.2	0.078
3	1	3	3	50	0.12	0.4	0.195	0.06
4	2	1	2	100	0.04	0.3	0.14	0.08
5	2	2	3	100	0.08	0.4	0.12	0.048
6	2	3	1	100	0.12	0.2	0.155	0.065
7	3	1	3	150	0.04	0.4	0.165	0.035
8	3	2	1	150	0.08	0.2	0.18	0.04
9	3	3	2	150	0.12	0.3	0.24	0.08

4. RESULTS AND DISCUSSION

4.1 Evaluation of experimental result



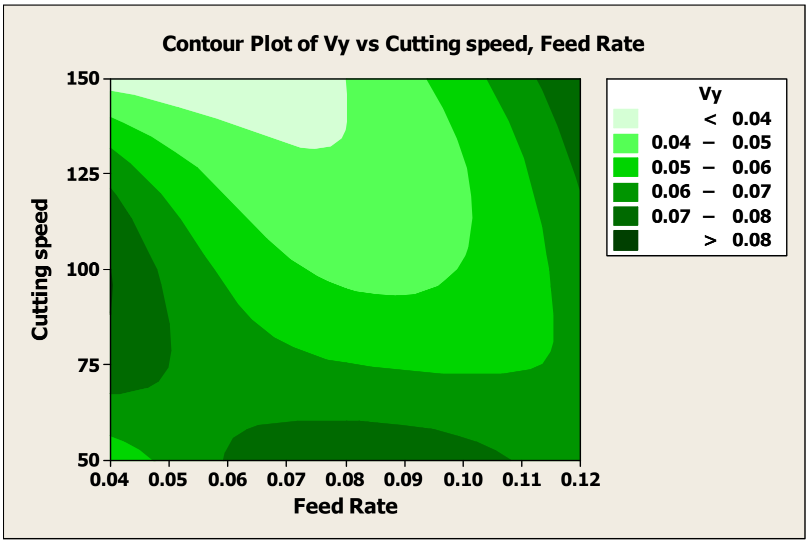
2 (a)



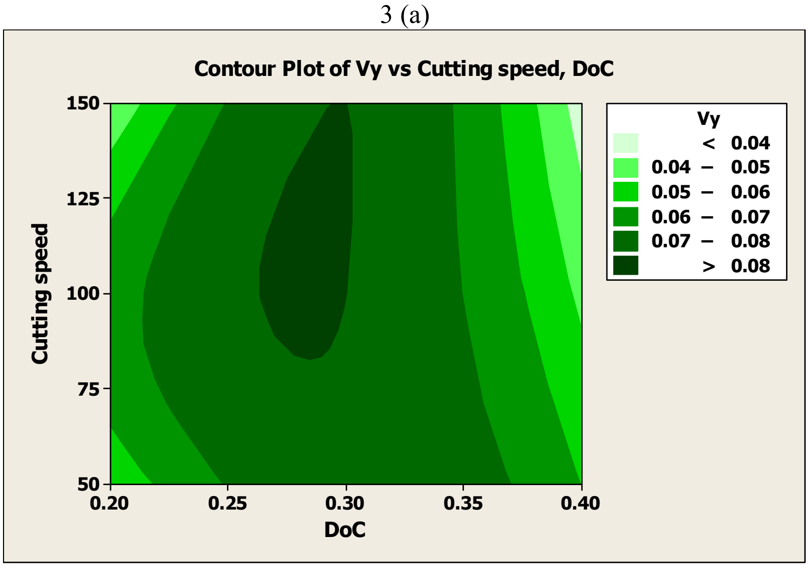
2(b)

Fig.2.The cutting parameter effect on tool vibration in Vx

The contour plot Fig. 2(a) and (b) shows the relationship between the cutting parameters and acceleration amplitude of tool in main cutting force (Vx). In Fig. 2 (a) and (b) shows that lower and higher cutting speed developed high acceleration amplitude of Vx and minimum tool vibration was observed in medium cutting speed. The depth of cut and feed rate increases with increase in acceleration amplitude of Vx. The cutting speed is the most dominant factor in affecting acceleration amplitude of Vx. In Fig. 3 (a) and (b) shows the relationship between the cutting parameters and acceleration amplitude of tool in radial cutting force (Vy). The higher cutting speed produced lower acceleration amplitude of Vy. The Fig 3 (a) and (b) shows that increase in feed rate and depth of cut increased the acceleration amplitude of Vy. The depth of cut is the most dominant factor in affecting acceleration amplitude of Vy.



3 (a)



3 (b)

Fig.3.The cutting parameter effect on tool vibration in Vy

4.2 Analysis of Variance (ANOVA) for vibration in main cutting force (Vx) and vibration in radial cutting force (Vy)

The analysis of variance (ANOVA) has been used to calculate the significant parameters affecting the acceleration amplitude tool vibration in main cutting force and radial cutting force. Table.3 shows the analysis of variance results for acceleration amplitude tool vibration in main cutting force and radial cutting force. This ANOVA carried out for 5% significance level and 95 % confidence level. Based on the ANOVA analysis, the % of the contribution of cutting speed, feed rate and depth of cut in affecting the acceleration amplitude of tool vibration in main cutting force were found to be 54 %, 27 % and 19 % respectively. Similarly, the % of the contribution of the depth of cut, feed rate and cutting speed in affecting the acceleration amplitude of tool vibration in main cutting force were found to be 74 %, 14 % and 12 % respectively. The cutting speed was the key factor affecting vibration in main cutting force and the depth of cut was the key factor affecting vibration in radial cutting force.

Table.3 Analysis of variance results for Vx and Vy

Cutting parameter	Degrees of freedom	Sum of square	Mean square	F ratio	P
Vibration in main cutting force (Vx)					
Cutting speed	2	0.0054889	0.0027444	988.00	0.001
Feed	2	0.0027722	0.0013861	499.00	0.002
Depth of cut	2	0.0019389	0.0009694	349.00	0.003
Error	2	0.0000056	0.0000028		
Total	8	0.0102056			
Vibration in radial cutting force (Vy)					
Cutting speed	2	0.0002976	0.0001488	334.75	0.003
Feed	2	0.0003296	0.0001648	370.75	0.003
Depth of cut	2	0.0017536	0.0008768	1972.75	0.001
Error	2	0.0000009	0.0000004		
Total	8	0.0023816			

4.3 Regression analysis for vibration in main cutting force (Vx) and vibration in radial cutting force (Vy)

The regression analysis was used to calculate and analysis the relation between a dependent and a number of independent variables. The dependent variables are tool vibration in main cutting force and radial cutting force. The independent variables are depth of cut, feed rate and cutting speed. The linear square regression was used to develop the prediction models for tool vibration in main cutting force and radial cutting force are shown in equation (1) and (2).

Regression analysis for vibration in main cutting force (Vx): $0.0744444 - 0.00403333V - 0.395833f + 1.82500d + 2.06667E\text{-}05V^2 + 5.72917f^2 - 3.08333d^2$ [1]

R-Sq = 99.95% R-Sq (adj) = 99.78%

Regression analysis for vibration in radial cutting force (Vy): $-0.179222 + 0.000430000V - 0.508333f + 1.73667d - 2.73333E\text{-}06V^2 + 4.16667f^2 - 2.93333d^2$ [2]

R-Sq = 99.96% R-Sq (adj) = 99.85%

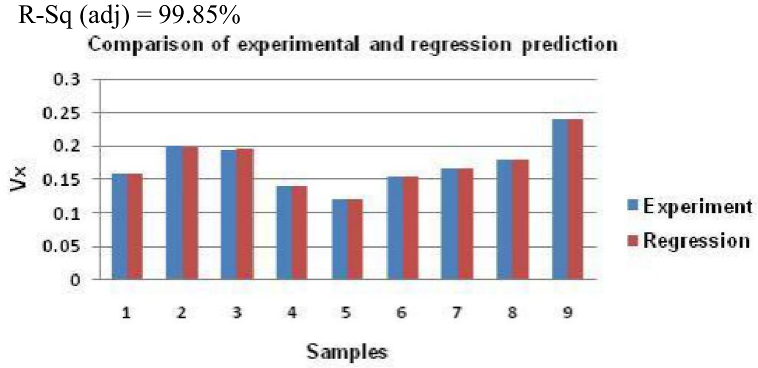


Fig. 4. Comparison of experimental and regression predicted results for Vx.

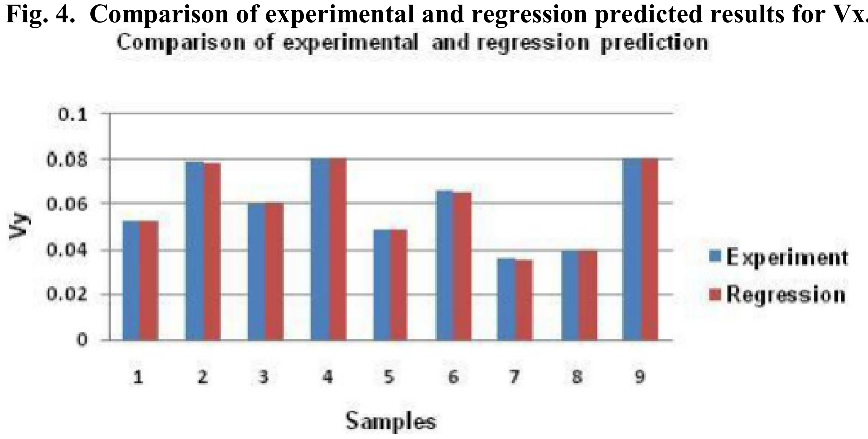


Fig. 5. Comparison of experimental and regression predicted results for Vy.

The relationship between the experimental values and regression predicted values are shown in Fig.4 and Fig 5. The linear square regression predicted values are very close to the experimental values. The R^2 values were obtained using regression for tool vibration in main cutting force is 99.78 % and in radial cutting force is 99.85 %.

4.4 Confirmation Test

Table 4 shows the comparison of experimental and regression prediction results for tool vibration in main cutting force and radial cutting force directions. The confirmation test was used to check the reliability of the developed model. The maximum % of error observed for tool vibration in main cutting force is 14.5 % and tool vibration in radial cutting force is 15 %. The reliable statistical analysis % of error value must be lesser than 20 % [11]. Therefore the developed model produced the results within the acceptable range. Hence the regression analysis was successfully used in the prediction of tool vibration in turning.

Table.4 Comparison of experimental and regression prediction results

Test	Regression prediction for Vx			Regression prediction for Vy		
	Experimental value	Predicted value	% of error	Experimental value	Predicted value	% of error
V1d3f2	0.2	0.229	14.5	0.08	0.092	15
V2d1f3	0.095	0.108	13.4	0.055	0.048	12.7
V3d2f1	0.16	0.181	13.1	0.04	0.039	2.5

5. CONCLUSIONS

This experimental work focused on prediction of acceleration amplitude tool vibration in main cutting force and radial cutting force directions in turning of austempered ductile iron using carbide inserts. The prediction model was developed for acceleration amplitude tool vibration in main cutting force and radial cutting force directions using the liner square equation. The analysis of variance was used to calculate the significant factor affecting the tool vibration. The experiment was conducted based on the Taguchi L_9 orthogonal array. Based on the experimental results the following conclusions are made

- The cutting speed with the 54 % contribution in affecting the tool vibration in main cutting force. The other factors affecting the tool vibration in main cutting force are feed rate and depth of cut with the contribution of 27 % and 19 % respectively based on analysis of variance result.
- The depth of cut with the 74 % contribution in affecting the tool vibration in radial cutting force. The other factors affecting the tool vibration in radial cutting force are feed rate and cutting speed with the contribution of 14 % and 12 % respectively based on analysis of variance result.
- The regression prediction model predicted the tool vibration with greater accuracy.
- Regression predicted the maximum 14.5 % deviation in acceleration amplitude of tool vibration in main cutting force and 15 % deviation in acceleration amplitude of tool vibration in radial cutting force.

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