An Experimental Investigation of Influence of Process Parameters on Cutting Tool Chatter

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***Abstract*—Cutting tool chatter, a relative movement between the cutting tool and work piece during machining is an important parameter which influences the cutting tool life and the surface finish of the machined part. Further the chatter will be influenced by self-excitation of the cutting tool, tool tip temperature and several controlled parameters such as process parameters including depth of cut, feed rate, and spindle speed. In the present study, the experimentation was carried out to investigate the influence of cutting tool chatter on surface roughness during the machining of mild steel material with Carbide insert cutting tool under different combinations of process parameters. The experimental work was carried out on a conventional lathe under different combinations of process parameters designed through 3k factorial design. The cutting tool chatter was captured with the help of tri-axial accelerometer, mounted on the cutting tool through a four channel FFT analyser and NVGate 9.10 software. The surface roughness of the machined part was measured with the help of Mitutoyo SJ-201 instrument. The combined effects of process parameters and surface roughness on cutting tool chatter were analysed by using analysis of variance (ANOVA) tool.**

Keywords—Cutting tool chatter, Surface roughness, Tri-axial accelerometer, FFT analyser, ANOVA

I. INTRODUCTION

Turning have been the most vital process among the various metal processing techniques. Turning process have a wide range of applications which includes machining of aerospace parts, automobile parts, manufacturing machine parts, etc. It is very important to optimise the turning process in order to achieve better efficiency. In order to use the machine tools efficiently, it is very important to optimise the cutting parameters such as spindle speed, feed rate and depth of cut. The combination of these process parameters will result in an optimised condition for an enhanced productivity and quality of the product and also indicating its condition. In the present study, two different cutting tool materials namely High Speed Steel (HSS) solid tool and Carbide cutting tool insert with the same tool geometry under the different combinations of process parameters designed through 3k factorial design have been employed to develop a relationship between the process parameters such as spindle speed, depth of cut, feed rate and output characteristics such as vibration and surface roughness using analysis of variance (ANOVA).

Three different materials (Mild Steel, PVC and Aluminium), were used in the experimentation of plain turning operation on lathe. It was concluded that the cutting force and feed had the maximum effect on the surface finish and vibration. Also the materials which have higher yield strength had more vibration whereas the materials which have lower yield strength had comparatively less vibration [1]. A study on the influences of various process parameters on the machine tool vibration and surface finish in a high precision CNC milling machine using an MEMS accelerometer reveals that spindle speed has more significant effect on vibration and depth of significant effect on surface roughness [2]. A mathematical model was developed to obtain low cutting tool vibration and the surface roughness where EN-31 tool steel was used as the work piece material which was machined on CNC end mill machine. The cutting parameters were varied throughout the experiment according to the full factorial design which consists of 27 experiments. The predicted surface roughness from the model was compared to the values measured experimentally [3]. An experiment was conducted to predict the cutting force of single point cutting tool and its vibrations using an artificial neural network (ANN) in turning operation and the predictions were made on the vibrations and cutting forces by giving different values for the cutting parameters [4]. Medium carbon steel AISI 1020 of 250mm length and 50mm diameter was chosen in an experiment where cutting speed, feed and depth of cut were chosen as the input parameters. An L27 array was chosen for the purpose of experimentation. It was concluded that the lowest feed, highest speed and the highest depth of cut resulted in optimal surface finish and according to ANOVA, it was concluded that the most significant parameter was depth of cut, followed by feed rate and lastly the cutting speed [5].

II. DESIGN OF EXPERIMENTS

The design of experiments is a precise layout or a plan that is developed in advance to actually carrying out the experiments. It provides a relationship between the input and output parameters such that the experiment can be carried out to obtain the exact information we need for the purpose of that particular study. It provides a detailed plan of all the possible combinations of the input parameters that can be achieved in order to obtain the suitable cutting condition. A well designed experiment provides the maximum amount of information that can be achieved with the minimal amount of experimental effort [6].

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Factorial Design

From the view of statistics, a full factorial design is a design in which there are two or more factors that contain discrete values and all possible combinations of the levels across all the factors. It takes into account each and every factor of the variable and all possible interactions of the factors at all levels. For two factors, the full factorial design would be a 2k design where in "k" is the number of levels in each factor. Similarly, the number of levels (k) in 3k design is 3 as there is one high, one medium and one low level. Therefore, the total number of experiments to be carried out will be 3*3= 27 experiments. One of the major advantages of the 3k factorial is that it reduces error within the cell. This would allow the study of each cutting condition to be carried out in a more detailed manner.

III. ANALYSIS OF VARIANCE (ANOVA)

Before The analysis of variance (ANOVA) is a form of statistical hypothesis testing that is used very commonly in the analysis if data. It is based on the null hypothesis which is used to determine the significance of a particular parameter from a set of parameters on a certain output. The initial null hypothesis assumes that there is not significance between the groups of data while the alternative hypothesis assumes that there is a significant difference among the groups that are given. The statistically significant result can be determined by calculating the p value.

IV. EXPERIMENTAL SETUP

In this study, mild steel material is used for the experimental work. Mild steel rod having a 20 mm diameter and 200 mm length each is used in this experiment. HMT LT20 precision centre lathe is used in the current study. The input parameters (or) process parameters considered in this study are spindle speed, feed rate and depth of cut whereas the output parameters considered for this study are vibration and surface roughness. Table 1 and Table 2 shows the input parameters considered with their levels and the DOE selected for this study.

Table 1: Input parameters with their levels

Levels	Spindle Speed (rpm)	Feed Rate (mm/rev)	Depth of Cut (mm)
1	*420*	*0.05*	*0.25*
2	*710*	*0.11*	*0.50*
3	*1200*	*0.22*	*0.75*

Figure 1: Experimental setup

Accelerometer was mounted on the cutting tool and the cutting tool vibrations were sensed with the help of a FFT-analyser. Figure 1 shows the experimental setup.

Table 2: DOE selected for this study

Trial No.	Coded Factor			Natural Factor		
	X1	*X2*	*X3*	*Spindle speed (rpm)*	*Feed rate (mm/rev)*	*Depth of cut (mm)*
1	*1*	*1*	*1*	*420*	*0.05*	*0.25*
2	*1*	*1*	*2*	*420*	*0.05*	*0.5*
3	*1*	*1*	*3*	*420*	*0.05*	*0.75*
4	*1*	*2*	*1*	*420*	*0.11*	*0.25*
5	*1*	*2*	*2*	*420*	*0.11*	*0.5*
6	*1*	*2*	*3*	*420*	*0.11*	*0.75*
7	*1*	*3*	*1*	*420*	*0.22*	*0.25*
8	*1*	*3*	*2*	*420*	*0.22*	*0.5*
9	*1*	*3*	*3*	*420*	*0.22*	*0.75*
10	*2*	*1*	*1*	*710*	*0.05*	*0.25*
11	*2*	*1*	*2*	*710*	*0.05*	*0.5*
12	*2*	*1*	*3*	*710*	*0.05*	*0.75*
13	*2*	*2*	*1*	*710*	*0.11*	*0.25*
14	*2*	*2*	*2*	*710*	*0.11*	*0.5*
15	*2*	*2*	*3*	*710*	*0.11*	*0.75*
16	*2*	*3*	*1*	*710*	*0.22*	*0.25*
17	*2*	*3*	*2*	*710*	*0.22*	*0.5*
18	*2*	*3*	*3*	*710*	*0.22*	*0.75*
19	*3*	*1*	*1*	*1200*	*0.05*	*0.25*
20	*3*	*1*	*2*	*1200*	*0.05*	*0.5*
21	*3*	*1*	*3*	*1200*	*0.05*	*0.75*
22	*3*	*2*	*1*	*1200*	*0.11*	*0.25*
23	*3*	*2*	*2*	*1200*	*0.11*	*0.5*
24	*3*	*2*	*3*	*1200*	*0.11*	*0.75*
25	*3*	*3*	*1*	*1200*	*0.22*	*0.25*
26	*3*	*3*	*2*	*1200*	*0.22*	*0.5*
27	*3*	*3*	*3*	*1200*	*0.22*	*0.75*

Figure 2: Surface roughness setup

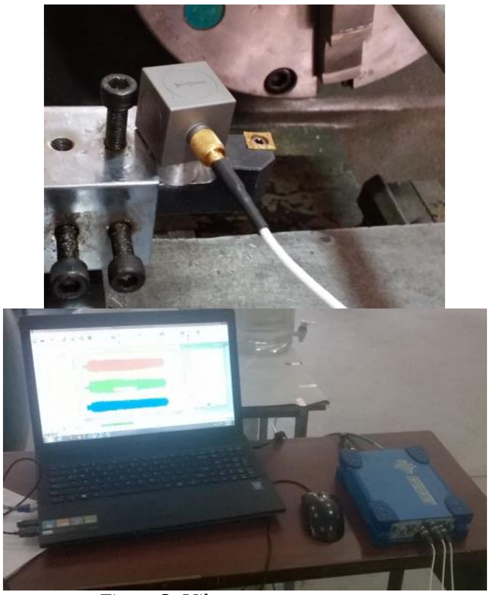

Figure 3: Vibraton measurement setup

Surface roughness of machined surface of the specimen was measured by using Mitutoyo SJ-201 instrument. The measured values of cutting tool vibration and surface roughness with Carbide insert cutting tool are listed in Table 3. The effect of these output parameters were further studied using Analysis of Variance (ANOVA) tool. Figure 2 and Figure 3 shows the surface roughness setup and vibration measurement setup.

Table 3: Recorded vibration values for mild steel using Carbide insert cutting tool

Trial No.	Spindle speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)	Vibration (g)			Surface roughness (µm)
				Tangential (X-axis)	Axial (Y-axis)	Radial (Z-axis)	
1	420	0.05	0.25	0.556	3.02	1.32	4.29
2	420	0.05	0.5	1.31	4.73	2.37	4.72
3	420	0.05	0.75	1.32	6.86	2.08	6.15
4	420	0.11	0.25	1.02	3.57	1.73	4.94
5	420	0.11	0.5	1.51	6.26	2.38	5.5
6	420	0.11	0.75	3.8	7.27	3.74	5.56
7	420	0.22	0.25	1.88	7.86	2.04	6.89
8	420	0.22	0.5	1.06	7.21	4.35	6.43
9	420	0.22	0.75	2.21	5.88	3.34	5.26
10	710	0.05	0.25	1.06	4.19	1.74	4.48
11	710	0.05	0.5	1.55	3.61	1.93	2.7
12	710	0.05	0.75	2.14	4.42	2.82	3.42
13	710	0.11	0.25	1.54	3.29	1.21	3.46
14	710	0.11	0.5	2.35	7.35	3.51	5.03
15	710	0.11	0.75	2.37	6.04	2.9	3.34
16	710	0.22	0.25	3.51	4.56	1.89	5.35
17	710	0.22	0.5	2.33	7.17	3.32	4.55
18	710	0.22	0.75	2.36	6.56	2.59	4.62
19	1200	0.05	0.25	0.616	2.11	1.05	4.7
20	1200	0.05	0.5	0.472	1.47	1.23	4.53
21	1200	0.05	0.75	1.07	3.69	2.85	1.67
22	1200	0.11	0.25	0.816	2.42	0.88	2.42
23	1200	0.11	0.5	1.55	3.69	2.43	3.58
24	1200	0.11	0.75	3.01	7.48	4.84	2.18
25	1200	0.22	0.25	2.31	7.98	1.83	4.05
26	1200	0.22	0.5	1.55	3.96	4.09	3.1
27	1200	0.22	0.75	0.143	0.69	0.24	2.14

V. RESULTS & DISCUSSION

The Analysis of Variance (ANOVA) is carried out which includes 3 input parameters spindle speed, feed rate and depth of cut using the 3k factorial design to finally obtain the ANOVA table for that particular condition. The design was considered to have 27 runs of a single block and 3 factors. Table 4 and Table 5 shows the ANOVA results on surface roughness and vibrations respectively.

From the ANOVA results table, the F and p values are the ones that are used to determine the most significant cutting parameter in the process. The value with the maximum value of F and minimum value of p is said to be the most determining factor. This is a case of two-way ANOVA where combinations of the input parameters are also considered.

From Table 4, we can conclude that the spindle speed is the most significant parameter followed by the feed rate provided and then the depth of cut. In Table 5, the individual parameters may not necessarily affect the tangential and axial vibrations too much, but when two parameters simultaneously act on the cutting process, it may cause heavy changes and can be a major influencing factor. Therefore, it is clear that combined effects of feed rate & depth of cut together is the influencing parameter on tangential and axial vibrations whereas depth of cut is the influencing parameter on radial vibrations.

Table 4: ANOVA results for Surface roughness (Ra)

Effect	Sum of Square (SS)	DOF	Mean of square (MS)	Frequency (F)	Percentage of Contribution (p)
Spindle speed (1)	27.11106	2	13.55553	21.30648	0.000023
Feed Rate (2)	2.28179	2	1.14090	1.79325	0.196501
Depth of Cut (3)	3.49435	2	1.74717	2.74619	0.092579
(1) x (2)	2.24182	1	2.24182	3.52367	0.077769
(1) x (3)	3.00812	1	3.00812	4.72814	0.044083
(2) x (3)	0.60289	1	0.60289	0.94761	0.343976
Error	10.81568	17	0.63622		
Total	47.80214	26			

Table 5: ANOVA results for vibrations

Effect	Sum of Square (SS)	DOF	Mean of square (MS)	Frequency (F)	Percentage of Contribution (p)
Tangential Vibrations (Tv)					
Spindle speed (1)	3.32651	2	1.663255	3.700428	0.046331
Feed Rate (2)	4.19485	2	2.097425	4.666375	0.024244
Depth of Cut (3)	1.13272	2	0.566359	1.260041	0.308832
(1) x (2)	0.01913	1	0.019130	0.042560	0.839007
(1) x (3)	0.80950	1	0.809498	1.800980	0.197244
(2) x (3)	3.41225	1	3.412252	7.591617	0.013517
Error	7.64110	17	0.449476		
Total	21.25720	26			
Axial Vibrations (Av)					
Spindle speed (1)	21.9488	2	10.97439	4.038558	0.036725
Feed Rate (2)	18.3814	2	9.19070	3.382163	0.058003
Depth of Cut (3)	2.7218	2	1.36088	0.500802	0.614710
(1) x (2)	0.2765	1	0.27649	0.101746	0.753630
(1) x (3)	3.5983	1	3.59827	1.324160	0.265776
(2) x (3)	19.0520	1	19.05205	7.011125	0.016916
Error	46.1958	17	2.71740		
Total	115.3618	26			
Radial Vibrations (Rv)					
Spindle speed (1)	1.06962	2	0.534809	0.559184	0.581840
Feed Rate (2)	2.64852	2	1.324262	1.384619	0.277269
Depth of Cut (3)	9.42108	2	4.710540	4.925236	0.020546
(1) x (2)	0.82819	1	0.828193	0.865940	0.365109
(1) x (3)	0.00349	1	0.003486	0.003645	0.952560
(2) x (3)	1.52605	1	1.526055	1.595609	0.223577
Error	16.25895	17	0.956409		
Total	32.73365	26			

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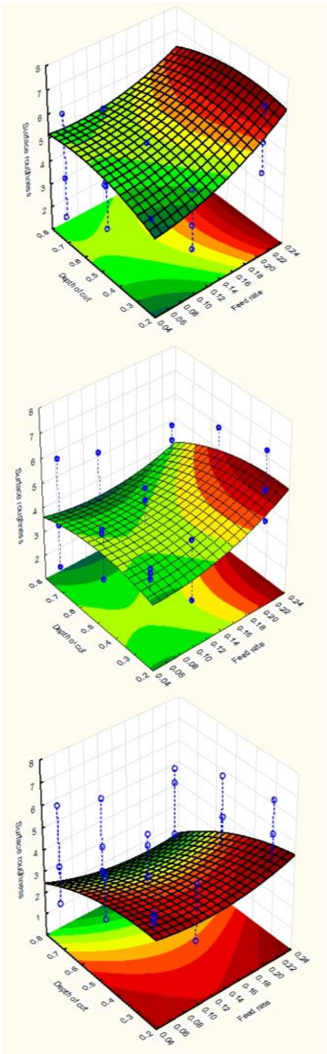

Figure 3: Surface plots for Ra

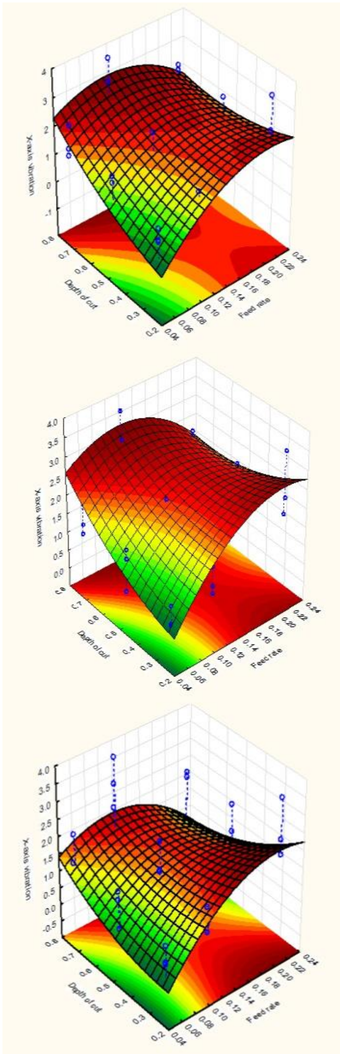

Figure 4: Surface plots for Tv

Surface plots were also generated for the particular influencing conditions so as to study the variation of each cutting condition that was found to be influential from the ANOVA. The surface plots are very helpful because they can be used to study the changes that occur on the output parameter in consideration and in turn allows the capability to conclude the behaviour of the machine tool for a said cutting condition. Figures 3, 4, 5 & 6 represents the surface plots for the influencing parameter on particular output parameter which is obtained from ANOVA results.

The surface plots in Figure 3 shows the variation of the surface roughness with respect to change in feed rate and depth of cut while keeping the spindle speeds constant at 420rpm, 710rpm and 1200rpm respectively. The plot shows the changes that occur in surface roughness when depth of cut is changed for different levels of feed rate. It is observed from the plot that as the feed rate increases, the surface roughness also increases gradually. It is clearly seen that all the plots are similar which proves the similarity in cutting for all three states. The region of maximum surface roughness is at the condition of maximum feed rate and almost for all levels of depth of cut. The region of least surface roughness is recorded at lower feed rates and varying depth of cuts. This shows that the depth of cut doesn’t affect much for this condition on surface roughness.

The surface plots in Figure 4 shows the variation of the tangential vibration with respect to change in feed rate and depth of cut while keeping the spindle speeds constant at 420rpm, 710rpm and 1200rpm respectively. The plot shows the changes that occur in tangential vibration when depth of cut is changed for different levels of feed rate. The region of maximum tangential vibration is at the condition of maximum feed rate and medium depth of cut. The region of minimum tangential vibration is in the region of lower feed rate and lower depth of cut. This is due to the proper cutting taking place at optimal depth of cut that prevents unwanted cutting forces or friction.

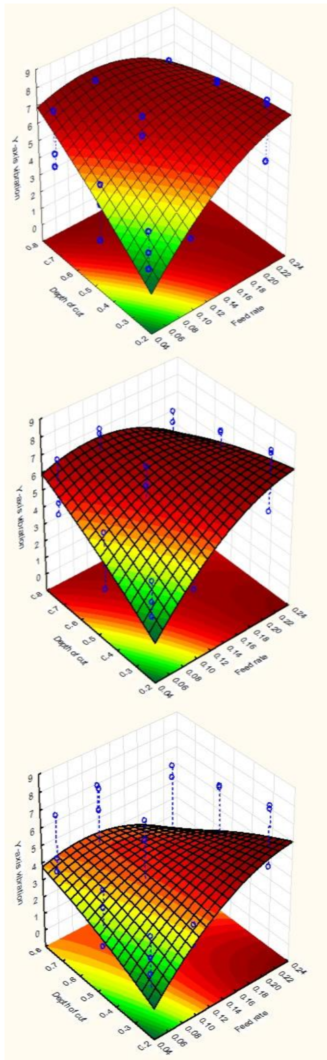

Figure 5: Surface plots for Av

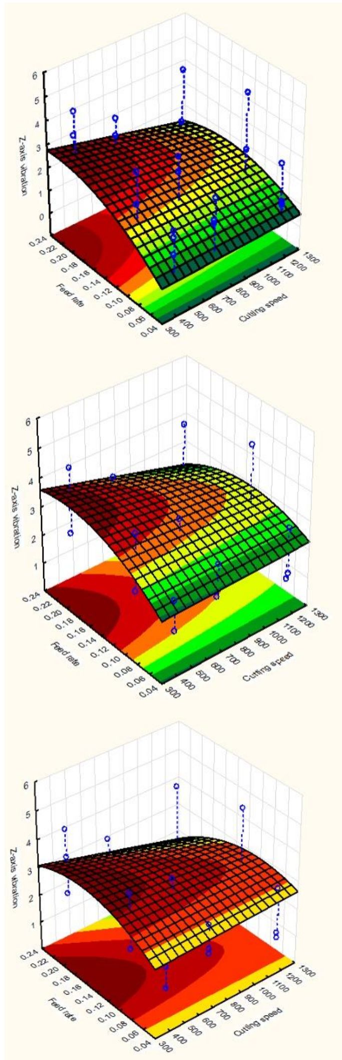

Figure 6: Surface plots for Rv

The surface plots in Figure 5 shows the variation of the axial vibration with respect to change in feed rate and depth of cut while keeping the spindle speeds constant at 420rpm, 710rpm and 1200rpm respectively. The plot shows the changes that occur in axial vibration when depth of cut is changed for different levels of feed rate. The region of maximum axial vibration is at the condition of varying feed rates and depth of cuts whereas the region of minimum axial vibration is in the region of lower feed rate and lower depth of cut. This is due to the proper cutting taking place at optimal depth of cut that prevents unwanted cutting forces or friction.

The surface plots in Figure 6 shows the variation of the radial vibration with respect to change in feed rate and depth of cut while keeping the spindle speeds constant at 420rpm, 710rpm and 1200rpm respectively. The plot shows the changes that occur in radial vibration when depth of cut is changed for different levels of feed rate. The region of maximum radial vibration is at the condition of varying feed rates and maximum depth of cuts whereas the region of minimum radial vibration is in the region of lower feed rate and lower depth of cut for the second and third plots. First plot is quite different when compared to the other two plots, this may be due to improper machining conditions maintained for all the states.

VI. CONCLUSION

During the course of this study, a set of experiments were carried out based on the 3k factorial design with the input parameters taken as spindle speed, feed rate and depth of cut for turning of mild steel specimen on HMT LT20 lathe using carbide insert cutting tool. The output parameters considered were the surface roughness and the cutting tool vibrations. ANOVA analysis was carried out to determine the influencing parameters. It was found that the spindle speed is the influencing parameter on surface roughness, a combination of depth of cut & feed rate is the influencing parameter on the tangential vibrations (X-Axis) and axial vibrations (Y-Axis), whereas depth of cut is the influencing parameter on radial vibrations (Z-Axis).

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