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Experimental investigation of CNC Turning Parameters for the Enhancement of Surface Finish on AISI D2

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Abstract: In contemporary machining industries, the challenge ascends to manufacture good quality of product with effective cost. In slighter way, but no less significant, turning process in CNC lathe machine has begun to see a technology fruition, in which surface roughness (Ra) plays a vital aspect concerning the quality and costing of turning operations. Taguchi method was implemented for integral design, such as selecting three parameters with their three different suitable levels and based on this, Taguchi orthogonal array (L_9) was selected. Turning parameters were elected viz. feed rate (F), spindle speed (V) and depth of cut (D). AISI D2 (high carbon high chromium) material was selected due to its ample use in thread rolling, shear blades, dies, burnishing rolls, etc. and is one of the most arduous specimens to be machined. Experimentation was implemented, based on the preferred parameters on CNC lathe machine with insert tool TnMg connected with accelerometer (sensor), data acquisition system (DAQ) and national laboratory (NI Lab.). Vibration responses on tool insert during testing were achieved with respect to surface finish. Result and analysis were executed using regression analysis and regression equation was engendered. Surface roughness (Ra) and Vibration effect (peak amplitude) were measured along each experiment and optimum value acquired were 2.6366 (μm) and 28.4760 (m/s^2) respectively. Analysis of variance (ANOVA), graphical main effect and interaction plots have been used to examine the effects of several parameters on number of cycles. Consequently, it was possible to decline production expenditure in an automatic machining environment.

Keywords: AISI D2; ANOVA; Surface roughness (Ra); Taguchi method; Turning; Vibration Analysis

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I. INTRODUCTION

During actual operation, machining of a product is required to get desired output with minimal cost, acceptable dimensional accuracy and excellent finish as well as not affecting to the environment. The never-ending rise of CNC lathe machines, cutting operation playing vital role in achieving great importance in the automatic world and turning process is the most extensively used among all the cutting operation in CNC lathe machines.[1-8] Turning operation is said to be removing of excess material from the cylindrical surface of the work piece which is rotating at a given feed rate (F), spindle speed (V) and depth of cut (D) and those parameters play a major significant in turning operation.[10][11]

For optimum results, Metal Removing Rate (MRR) and Surface Roughness (Ra) were considered to be tremendously influencing in turning process. Surface roughness stimuluses the coefficient of friction, fatigue strength, corrosion resistance and wear rate. In real practice, there are many additional factors which disturb the Ra: cutting condition, tool variables and work piece variables.[1] The experimentation was carried out by Taguchi technique of orthogonal (L_9) array. Taguchi method was discovered by Dr. Genichi Taguchi in the 1950's to select or determined the optimal parameters for turning operation. It was also the conventional approach for robust experimentation design that pursue to acquire a best amalgamation set of levels and factors.[2] From Design of Experiment, Taguchi's method was examined to scrutinize the consequence of cutting parameters on surface roughness (Ra) for AISI D2 workpiece while machining with TnMg insert.

Specimen AISI D2 was selected due to its excellent mechanical properties and high wear resistance and is one of the most difficult material to be machined. D2 workpiece having properties like air hardening, high chromium and high carbon tool steel are extensively used for manufacturing numerous cutting tools and dies.[3][4][11] Meenu Sahu, et al. [4]found out that optimal technique for turning operation parameters (feed rate, depth of cut and cutting speed) for specimen AISI D2 steel to attain least tool wear, extreme material removal rate (MRR) and minimum work piece surface temperature. The trials exposed that depth of cut and cutting speed are the utmost vital cutting parameter persuading wear and tear of the tool. Ankush Singal, et al. [5]concluded that cutting speed was the most contributing factor influencing Surface Roughness whereas feed rate was the least committing factor affecting Ra value. Optimal machining circumstances for minimizing Ra results and maximizing MRR from Taguchi's method were: feed rate 0.2 mm/rev, depth of cut 0.6 mm, cutting speed 1000 m/min and depth of cut 0.5 mm, feed 0.3 mm/rev, cutting speed 1400 m/min.

(ANOVA) Analysis of variance can be beneficial for influential of any specified series of experimental consequences input parameter by (DOE) for machining method and it can also be used to construe experimental information. ANOVA is a group of associated procedures and their statistical models, in which the observed variance in a variable is partitioned into components attributable to different sources of variation. In easy way, it delivers an arithmetical trial of whether the means of numerous groups are all equivalent. So, it oversimplifies t-test to more than 2 groups.[6][8] ANOVA was used to carry out result and analysis for comparing different parameters and plotting graphs for surface roughness (Ra) on a workpiece and their effect of vibration (peak amplitude) on tool insert.

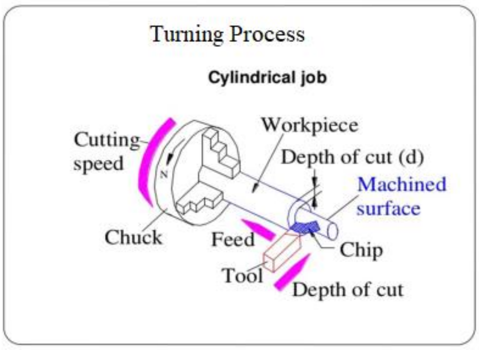

Figure1: Turning Process

In the present study, it was obtained that a lot of work had been completed on turning process parameter, surface roughness on variety materials. It was also seen that various analyzing techniques and methodology were used to increase the quality of the surface finish of work piece, this guides to a very critical area for manufacturing field. As various parameters of machining on D2 material has been investigated but seldom study was done on turning operation of D2 material with vibration response dominating on Y-axis on tool insert. Hence, the motive was to determine the results of the Computer Numerical Control (Turning Process) cutting process parameters on AISI D2 steel specimen and their response on tool insert by applying analysis of variance (ANOVA) and Taguchi's orthogonal array design under dry setting.

II. EXPERIMENTAL DETAILS

The purpose of the experimentation was to investigate the consequence of cutting process parameters on surface roughness and their vibration effect on the cutting tool. The experimentations were executed using orthogonal array (Taguchi's method) that helped in reducing the no. of experimentations and trials were carried out with selected parameters and their three level L_9 orthogonal array on AISI D2 steel workpiece. AISI D2 specimen was elected because of its nascent variety of function in the arena of tools and die manufacturing in innumerable factories. Feed rate (F), Cutting speed (V) and depth of cut (D) were the three cutting parameters used with their levels as shown in table 1. Instruments used in the experimentation are shown in table 2.

Table 1: Cutting parameters and their levels

Cutting parameters	**Levels**		
	Minimum	Average	Maximum
V (m/min)	180	230	280
F (m/rev)	0.15	0.2	0.25
D (mm)	180	230	280

Table 2: Technical specification of instruments used

Machine	JYOTI DX 150, FANUC controlled CNC lathe. Max. power - 9.25 kW; max. spindle speed - 4500 rpm.
Cutting inserts/conditions	TnMg 120404 (ISO)/ Dry conditions
Surface Roughness Tester	Mitutoyo SJ 410
Accelerometer/DAQ system	Triaxial / Nation Institute Laboratory

2.1Workpiece material

AISI D2 steel was carefully chosen due to its air hardening, high-carbon, high-chromium, abrasion resistant properties. It offers hardness between 55-620HRC and can be machined in the annealed condition. During hardened condition, due to its high chromium property it can offer mild corrosion resistance. [2][3] Spectroscopy was carried out at Ramelex Testing and Research Institute, Pune to find out chemical composition of the material as shown in table 3. Total 9 workpiece having 30 mm diameter and 80 mm length were selected for the experimentation.

Table 3: Material properties of AISI D2

Composition	C	Cr	Mn	Si	Mo	W	S	P
Weight (%)	1.55	11.8	0.4	0.4	0.7	0.6	0.03	0.03

2.2Experimental Setup and Testing

The trials were performed on a FANUC controlled Computer Numerical Control lathe machine under dry cutting environment situated in the workshop of M. E. S. College of Engineering, Pune, India. Before actual experimentation, to ensure consistency a small thickness of 0.5 mm from the workpiece was machined.

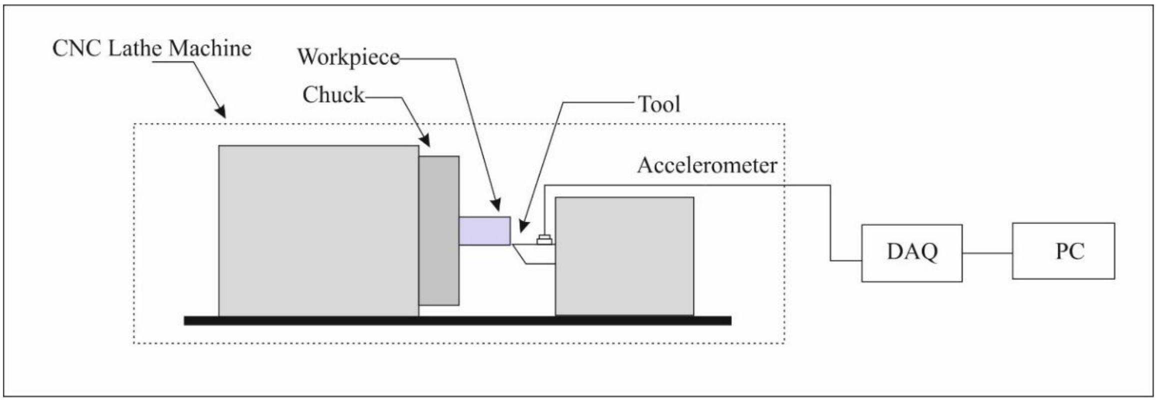

Figure 2: Block diagram of experimental setup

During turning operation vibrations were occurred due to dynamic motion dominating on Y-axis between work-piece and cutting tool. Machine tool vibration was sensed by a sensor, which was connected to the triaxial accelerometer and the signal was transfer through signal conditioners and Data Acquisition Unit (DAQ) to the computer illustrated in figure 2. The experimental setup consists of CNC lathe machine, tri axial accelerometer, signal convertor, DAQ system, NI Lab. View, laptop and connecting wires. After the turning process conducted on CNC lathe machine, all the workpieces were placed on to the table for testing their surface roughness (Ra) as shown in figure 3. Before preliminary the measurement of surface finish, a run-up is required and Mitutoyo SJ 410 (Ra tester) is normally set to 0.5 mm, but it can be shortened to 0.15mm using the narrow part measurement function. Stylus at the tip of the instrument was used to determine Ra value as shown in figure 3 and their function samples displacement for a specified time without engaging detector traverse, which enables as a simplified vibration meter or displacement gage incorporated in another system.

Figure 3: Surface roughness testing on AISI D2 specimen after machining

Table 4: L_9 Orthogonal array of Taguchi design and Results

Run order	V (m/min)	D (mm)	F (mm/rev)	Ra (µm)	Va (m/s^2)
1	180	0.5	0.15	2.6366	29.2560
2	180	0.75	0.20	2.8233	28.4760
3	180	1.00	0.25	4.0620	31.2196
4	230	0.50	0.20	2.9170	34.100
5	230	0.75	0.25	4.1230	35.8973
6	230	1.00	0.15	4.2190	43.3610
7	280	0.50	0.25	8.8110	65.200
8	280	0.75	0.15	9.7190	57.1965
9	280	1.00	0.20	15.2610	59.1350

It can be noticeable that minimum value for surface roughness from the above experiments is 2.6366 µm which was derived from the selected cutting parameters such as feed rate (F) - 0.15 mm/rev, spindle speed (V) - 180 m/min and depth of cut (D) - 0.5 mm. Whereas, optimum result for vibration is 28.4760 m/s^2 where V -180 m/min, F - 0.20 mm/rev and D - 0.75 mm. Increase in the value of input parameters is resulting into the occurrence of built up edge which develops number of layers of burrs resulting lower surface finish.

III. RESULT AND ANALYSIS

Vibration and surface roughness values were scrutinized using (ANOVA) Analysis of Variance method to recognize the influences of the turning operation parameters on surface roughness and vibrations and to find out the most influencing parameter affecting these responses. Cutting parameters were considered as input whereas surface roughness and vibration were considered as output parameters during ANOVA analysis.

3.1Regression model and equation

With the help of Minitab 16, a regression model and equation were generated for surface roughness (Ra) and vibration (peak amplitude) as shown in table 5 and table 6 respectively. It was evident that the most significant cutting parameter affecting is spindle speed while the other two parameters depth of cut and feed rate have a scanty part to play on surface roughness.

Table 5: ANOVA readings for Ra

Source	DF	SS	MS	F-value	P-value	(%)
Spindle Speed	2	122.189	61.094	14.82	0.063	82.10
Depth of Cut	2	14.938	7.469	1.81	0.356	10.03
Feed rate	2	3.452	1.726	0.42	0.705	2.32
Error	2	8.244	4.122			
Total	8	148.822				
S = 2.03028, R-seq.= 94.46 %, R-seq. (Adj.) = 77.84%						

For instance, **Equation (1)** is used to calculate a response surface roughness.

Surface Roughness (Ra) = 6.064 – 2.890 V[180] – 2.311 V[230] + 5.200 V[280] - 1.213 D[0.50] – 0.571D[0.75] + 1.784 D[1.00] - 0.476 F[0.15] + 0.875 F[0.20] - 0.398 F[0.25].

Table 6: ANOVA readings for Va

Source	DF	SS	MS	F-value	P-value	(%)
Spindle Speed	2	1534.92	767.46	36.69	0.027	94.7
Depth of Cut	2	24.77	12.39	0.59	0.628	1.53
Feed rate	2	20.49	10.24	0.49	0.671	1.27
Error	2	41.84	20.92			
Total	8	1622.02				
S = 4.57364, R-seq.= 97.42 %, R-seq. (Adj.) = 89.68%						

For instance, **Equation (2)** is used to calculate a response vibration.

Vibration (Peak Amplitude) = 42.65 - 13.00 V[180] - 4.86 V[230] + 17.86 V[280] + 0.20 D[0.50] – 2.13 D[0.75] + 1.92 D[1.00] + 0.62 F[0.15] – 2.08 F[0.20] + 1.46 F[0.25].

Further analysis of the data was done to understand the main effect plot and interaction effect plots of cutting parameters which are affecting surface finish and their vibration response. The plots represent the variation of individual response with the selected three cutting parameters such as feed rate, spindle speed and depth of cut separately. The relative influence amongst the parameter levels are determined more accurately in ANOVA analysis and was performed for the number of cycles in order to find out the most influencing parameter affecting this response. In the following plots (4, 5, 6 & 7), the x-axis demonstrates the obtained selected parameter at three different levels whereas, y-axis represents their response value. Main Effect Plot were used to illustrate the optimum design circumstances to attain minimum surface roughness (Ra) on workpiece and their vibration (peak amplitude) effects on tool insert while, Interaction Effect Plots were used for the effect of level of one factor depending on the level of the other factors and the greater is the degree of interaction when the larger is the difference between two lines.

3.2Regression analysis for surface roughness (Ra)

Figure 4 represents surface roughness (Ra) main effect plot on workpiece and there was tremendous increase in Ra value when spindle speed is 230m/min to 280 m/min and depth of cut is constantly increasing which results in affecting the surface of the workpiece. On the contrary view, feed rate increases initially but declines from mid-range. In the interaction effect plot, individual effect of each selected cutting parameters (V D F) was compared with the other remaining two parameters which are affecting the surface roughness value and are shown in figure 5. It was clear that the maximum spindle speed (280 m/min) and depth of cut (1mm) are causing low surface finish throughout the process, while feed rate was slightly changing Ra (μm) results

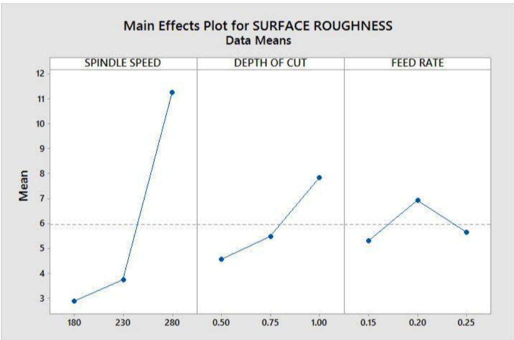

Figure 7: Main Effect Plot

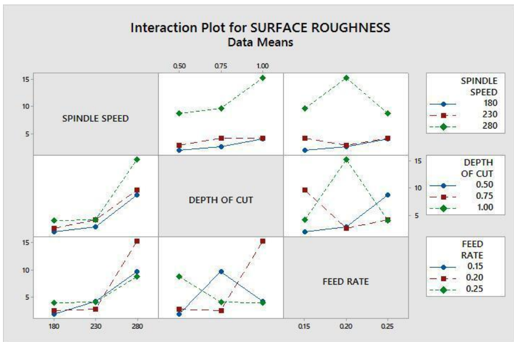

Figure 8: Interaction Effect plots

3.2Regression analysis for vibration (peak amplitude) (Va)

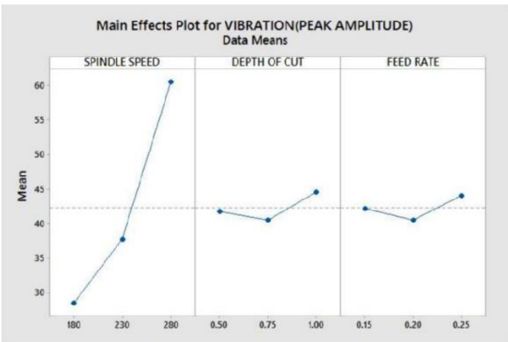

Fig. 9: Main Effect Plot

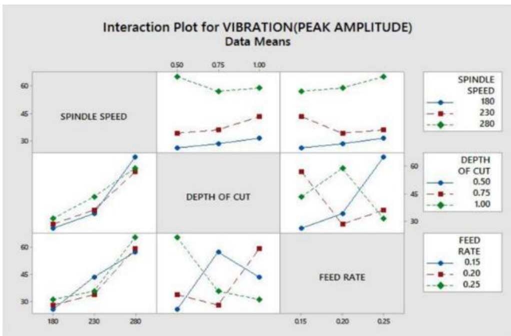

Fig. 10: Interaction Effect plots

Figure 6 illustrates the main effect plot for vibration (peak amplitude) generated on tool insert. Spindle speed was seen to be the major cause of vibration as it was rising extremely. Whereas, feed rate and depth of cut were almost akin to each other not causing major disturbance on the tool. Vibration (peak amplitude) occurred on tool insert was characterized in the interaction effect plot as shown in figure 7 where two cutting parameters are interaction with the remaining one parameter which are causing disturbance on the tool. Spindle speed (180 m/min) was major parameter precipitating the value of vibration (m/s^2) to increase whereas depth of cut and feed rate are marginally affecting it.

IV. CONCLUSION

Based on the trials carried out on D2 steel during turning operation, following were the consequences:

- From the analysis, a regression equation was been established for Surface Roughness (Ra) and vibration (peak amplitude), thus results can be predicted by knowing the values V F D.
- For Ra, the optimal setting for turning process parameters are V-180m/min, F-0.15 mm/rev and D-0.50 mm. This research illustrates, how Taguchi's method was used to acquire minimum no. of experiments and low cost with optimum condition.
- The optimized machining condition for optimum Va from triaxial accelerometer are obtained from this condition: V-180m/min, F-0.20 mm/rev and D-0.75 mm.
- The validation of experiment was inveterate that the error occurred was less than 3.0 percent between actual value and equation**.** This research can be extended for D2 material using different parameters**.**

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Conflict of Interests

There was no conflict of concern regarding the publication of this paper by the authors.

Nomenclature

V : Spindle Speed
D : Depth of cut
F : Feed rate
Ra : Surface roughness
Va : Vibration (peak amplitude)

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