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Multi-Objective Optimization of Cutting Parameters in CNC Turning of AISI 52100 Using Taguchi Method

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Abstract- ***In present time the technology of CNC turning machine has been advanced significantly, in order to meet the advance requirements in various manufacturing fields, especially in the precision turning metal cutting industry. Among the several CNC industrial machining processes. It is widely used in a variety of products/components manufacturing in the industries. The objective of the paper is to optimize the choice of cutting parameters in terms of cutting speed, depth of cut, feed rate and noise radius during turning process of AISI 52100 steel when multiple objectives are simultaneously taken into consideration like surface roughness, metal removal rate and cutting forces. Taguchi orthogonal array is designed with three levels of turning parameters with the help of software Minitab14. It is predicted that Taguchi method is a good method for optimization of various machining parameters as it reduces number of experiments. In order to improve the machining characteristics, effort to minimize the value of Ra, maximize the value of MRR and minimize machining force by selecting optimal machining process parameters like cutting speed, feed rate, depth of cut and insert nose radius are required to be study in details The results indicate the optimum values of the input factors and the results are conformed by a confirmatory test.***

Keywords: Surface Roughness, CNC turning, MMR, Taguchi method, Noise Radius, Minitab, Machining Force

1. Introduction

In present time the technology of CNC turning machine has been advanced significantly, in order to meet theadvance requirements in various manufacturing fields, especially in the precision turning metal cutting industry. Among the several CNC industrial machining processes. It is widely used in a variety of products/components manufacturing in the industries. The material removal rate (MRR) and Surface roughness (Ra) are an important controlling factor of machining operation. MRR and Ra are measurement of productivity and quality of the machining component. In order to improve the machining characteristics, effort to minimize the value of Ra, maximize the value of MRR and maximize machining force by selecting optimal machining process parameters like cutting speed, feed rate, depth of cut and insert nose radius are required to be study in details.

Arafa S Sodh[1] addressed the increasing interest in TC21 Ti-alloy within the realm of materials engineering and aimed to analyze its machinability aspects. To efficiently achieve this goal with minimal experimental trials, the researchers utilized the orthogonal array (OA) L9 Taguchi approach. This method involved investigating three cutting parameters at three different levels. The optimal cutting conditions were determined through the experimental work conducted based on these parameters. Md Tanveer et al. [2] did a research study to find the most suitable cutting parameters for machining hardened steel on a (CNC) lathe machine. They also explored the influence of on ceramic tools while performing dry cutting operations. To enhance the results of hard-turning, a multi-objective optimization (MOO) model based on integrated fuzzy TOPSIS was employed. The findings of the study demonstrated that a combination of speed of cutting at 98 m/min, feed at 0.1 mm/rev, and doc at 0.2 mm produced the most favorable multi-objective outcomes. Furthermore, the ANOVA analysis indicated that the feed rate significantly affected the response variables.VikashMarakini[3] utilized a blend of Taguchi design of experiments and the machining settings with the goal of enhancing of AZ91 alloy. They employed the Taguchi L9 design to determine cutting conditions for dry face milling, and then fine-tuned the multiple objectives using Grey Relational Analysis. The effect of individual parameters on both attributes and the grey relational grade was assessed using, performed separately for each attribute. Furthermore, an analysis of variance was conducted to evaluate the impact of variables on surface hardness and roughness. To validate the findings, confirmation experiments were carried out, confirming the projected trends based. This investigation demonstrated the successful synergy between Taguchi design and Grey Relational Analysis in tackling challenges related to surface characteristics. Pytlak and colleagues [4] introduced an innovative method for hard turning of cemented 18 HGT steel. They enhanced the wipers' geometry using CBN (cubic boron nitride) and considered cutting depth, feed rate, and cutting velocity as critical factors to achieve optimal results.To attain cost-effective manufacturing and reduce cutting pressures, Sieben and his team (2010) applied the (DACE) technique to experimentally demonstrate the AISI 6150 steel, utilizing PCBN (polycrystalline cubic boron nitride) tools. They comprehensively analyzed various criteria, including feed rate, cutting depth, and cutting velocity, to evaluate the hard turning process. Cappellini et al. [5] conducted a study with a focus on improving surface layers during hard cutting of AISI 52100 steel discs. They employed PCBN (Polycrystalline Cubic Boron Nitride) inserts for this purpose. The study revealed that exceeding the austenizing temperature resulted in the burial of martensite, leading to the formation. The key parameters investigated.

The surrounding white under a microscope. Additionally, it was noted that the tool gradually reduced the thicknesses of the layers. Higher cutting speeds or feed rates led to thicker white layers, while lower speeds or feed rates produced thinner layers. D. PhilipSelvaraj et al. [6] the objective was to assess (cutting rate, fr, and doc) on the roughness surface of AISI 309

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Austenitic treated steel. The researchers utilized Taguchi's technique to collect data and employed a tungsten carbide cutting tool coated with TiC and TiCN to analyze the cutting characteristics of AISI 304 steel bars. The analysis encompassed Symmetrical displays, (ANOVA). The outcomes were verified through certification tests, confirming the reliability of the conclusions pertaining to surface roughness.

2. Experimental Setup and Procedure

2.1Specimen Material Details

Workpiece material used for experimental work was AISI 52100, as shown in Figure 1. AISI 52100 round bars bearing steel is one kind of special steel with features of high wear resistance and rolling fatigue strength. Experimental trials were conducted on 80 mm length and 40 mm diameter cylindrical steel bar. The total length to be machined during each reading was 40 mm and 30 mm length, that was provided for clamping the work pieces into three jaw chuck. Each piece was used to perform three experiments. A pre-cut of 0.5 mm depth was performed on each work piece prior to actual turning in order to remove the rust or hardened top layer from the surface and to minimize any effect of non-homogeneity on the experimental results.

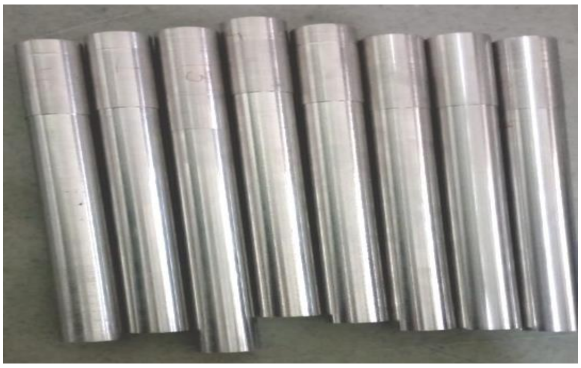

Figure 1: Workpiece material AISI 52100

2.2 Cutting Tool and Tool Holder

Triangular shape Tungsten carbide tool insert with TiAlN, 5µm coating was considered for the experimental analysis. Sandvik inserts with the ISO TNMG 16 04 12 designation were mounted on the tool holder designated by ISO as PTGNR 2020 K16 having rake angle of 7°, clearance angle of 6°and 0.4 mm nose radius. An insert mounted on the tool holder is shown in Figure 2.

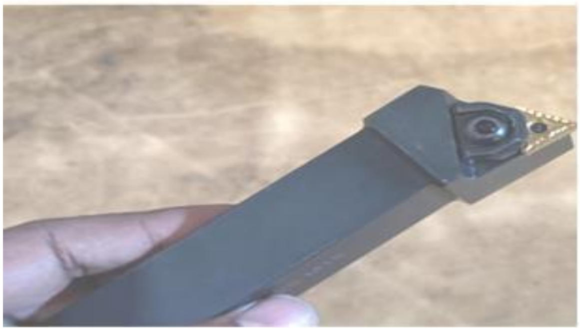

Figure 2: Cutting Tool with tool holder

2.3 CNC lathe

The spindle speed is directly controlled with the gear mechanism provided on the control unit. Shown in Figure 3, MCL 10 CNC lathe machine used for experimentation consists of tool holder unit, head stoke, and tail stoke for machining the workpiece. The input power supply to the machine is 3 Phase A.C 415V. The operating frequency is 50Hz. The control voltage for the machine is 220V. Maximum diameter of machining is 30mm. maximum length of machining is 60 mm

Figure 3: MCL 10 CNC lathe

3. Design of Experiment

Table 1 represents four factors like feed rate, speed, depth of cut and tool nose radius and three levels for L9 orthogonal array of AISI 52100.

Table 1: Control Factor and their Factors

CUTTING PARAMETERS	UNIT	LIMITS		
		Level 1	Level 2	Level 3
Feed rate (A)	mm/mi	10	40	70
Speed (B)	RPM	500	1000	1500
Depth of cut (C)	mm	0.3	0.5	0.8
Tool nose radius (D)	mm	0.4	0.6	0.8

The L9 technique is used for turning of AISI 52100 alloy using MCL 10 CNC lathe machine. The machining results were analyzed using experimental design, which was done using. The main purpose of the ANOVA is to investigate the design parameters and to indicate the parameter that affect the quality characteristic significantly.

Table 2: Design of matrix for turning of AISI 52100 using L9 orthogonal array

Exp no.	Design of matrix				Feed rate (mm/min)	Cutting spee (rpm)	Depth of cut (mm	Nose radius (mm)
	A	B	C	D				
1	1	1	1	1	10	500	0.300	0.400
2	1	2	2	2	10	1000	0.500	0.600
3	1	3	3	3	10	1500	0.800	0.800
4	2	1	2	3	40	500	0.500	0.800
5	2	2	3	1	40	1000	0.800	0.400
6	2	3	1	2	40	1500	0.300	0.600
7	3	1	3	2	70	500	0.800	0.600
8	3	2	1	3	70	1000	0.300	0.800
9	3	3	2	1	70	1500	0.500	0.400

This analysis helps to find out the relative contribution of machining parameter in controlling the response of the turning operation.fter machining, the surface roughness, material removal rate and machining force of machined specimen is measured. The Table 2 shows Design of matrix for turning of AISI 52100 using L9 orthogonal array

Table 3 shows the obtained MRR, machining force and measured Ra values. SJ-201P is a device for measuring the surface roughness. MRR and machining force are found to formula.

Table 3: Results of L9 turning of AISI 52100

Exp no.	Surface roughness (µm)	Material removal rate (mm^3/min)	Machining force (N)
1	2.023	235.619	3.000
2	7.141	392.699	2.500
3	7.682	628.319	2.667
4	1.765	1570.796	20.000
5	7.027	2513.274	16.000
6	7.214	942.478	4.000
7	1.581	4398.230	56.000
8	4.927	1649.336	10.500
9	7.649	2748.894	11.667

1. Result and Discussions

The experiments are conducted to study the effect of process parameters over the output response features with the process parameters. The S/N ratio results for the surface roughness, material removal rate and machining force are given. In the present study all the designs, plots and analysis have been carried out using Minitab 14 statistical software. The effect of different process parameters on MRR, surface roughness and machining force are calculated and plotted as the process parameters changes from one level to another. The use of ANOVA technique to analyze the results and hence, make it fast to reach on the conclusion.

4.1 Analysis of Variance for Surface Roughness

Table 4 gives the sum of squares, mean squares and % contribution of cutting parameters on surface roughness of AISI 52100 after turning under L9 orthogonal array. It can be seen from the table that the % contribution of Nose radius is slightly larger than other parameters followed by depth of cut and feed rate. Speed adds no contribution to the surface roughness of the material during turning operation.

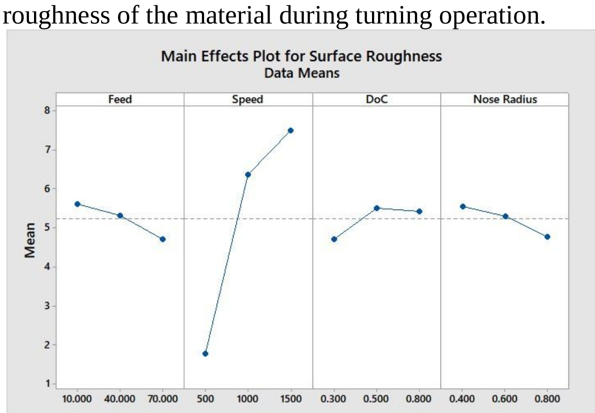

Figure 4: Main effect plot for surface roughness of AISI 52100 turning under L9 array

It can be seen from figure 4 that the increase in speed increases the surface roughness of the work piece. The surface roughness value decreases with increase in feed and Nose radius of the tool.The surface roughness increases till a certain value of depth of cut and then decreases. From Figure 5.we can see that higher feed rate, lower speed, low depth of cut and high nose radius is required to obtain the lowest surface roughness.

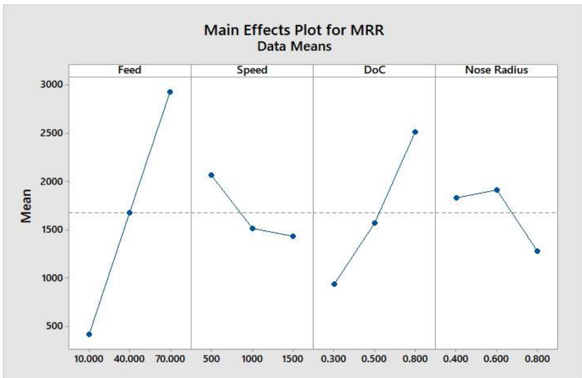

Figure 5: Main effect plot for material removal rate of AISI 52100 turning under L9 array

It can be seen from figure 5 that the increase in speed decreases the material removal rate of the work piece. The material removal rate value increases with increase in feed and depth of cut of the tool. The material removal rate increases till a certain value of nose radius and then decreases. From figure 5 we can see that higher feed rate, higher speed, large depth of cut and high nose radius is required to obtain the maximum material removal rate.

1.2 Analysis of Variance for MRR

Table 5 gives the sum of squares, mean squares and % contribution of cutting parameters on Material Removal Rate of AISI 52100 after turning under L9 orthogonal array. It can be seen from the table that the % contribution of Speed and Nose radius are larger compared to other parameters. Whereas Feed has the lowest % contribution.

The change in feed rate of the cutting tool from a value of 10 mm/min to 70 mm/min increases the average value of material removal rate from a value of 418.879 mm^3/min to a value of 2932.153 mm^3/min. The change in speed from a value of 500 RPM to a value of 1500 RPM decreases the material removal rate from a value of 2068.215 mm^3/min to a value of 1439.897 mm^3/min.

The change in nose radius of the material from a value of 0.4 mm to 0.6 mm increases the material removal rate from a value of 1832.596 mm3/min to a value of 1911.136 mm3/min and the change in nose radius from 0.6 mm to 0.8 mm decreases the value of material removal rate from 1911.136 mm3/min to 1282.817 mm3/min. The change in depth of cut of the tool from 0.3 mm to 0.7 mm increases the value of material removal rate from 1308.997 mm3/min to 2513.274 mm3/min.

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Table 4: ANOVA for Ra

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% contribution
Feed	2	1.262	0.631	0.07	0.937	33.09%
Speed	2	55.036	27.518	49.4	0	0.00%
DoC	2	1.145	0.5726	0.06	0.942	33.26%
Nose Radius	2	0.9355	0.4677	0.05	0.953	33.65%

Table 5: ANOVA for MRR

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% contribution
Feed	2	9474820	4737410	5.51	0.044	2.02%
Speed	2	703209	351605	0.15	0.863	39.57%
DoC	2	3750450	1875225	1.03	0.411	18.84%
Nose Radius	2	703209	351605	0.15	0.863	39.57%

Table 6: ANOVA for Machining Force

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% contribution
Feed	2	818.9	409.4	1.65	0.268	15.06%
Speed	2	699.4	349.7	1.31	0.338	18.99%
DoC	2	576.2	288.1	1	0.422	23.71%
Nose Radius	2	208.9	104.4	0.3	0.752	42.25%

Analysis of Variance for Machining Force

Table 6 gives the sum of squares, mean squares and % contribution of cutting parameters on Machining Force of AISI 52100 after turning under L9 orthogonal array. It can be seen from the table that nose radius has the highest contribution on machining force during turning of the AISI 52100 followed by depth of cut, speed and feed rate.

It can be seen from figure 6 that the increase in speed decreases the machining force of the work piece. The machining force value increases with increase in feed and depth of cut of the tool. The machining force increases till a certain value of nose radius and then decreases. From figure 6 we can see that low feed rate, high speed, small depth of cut and low nose radius is required to obtain the lowest machining force.

The change in feed rate of the cutting tool from a value of 10 mm/min to 70 mm/min increases the average value of machining force from a value of 2.722 N to a value of 26.056 N.

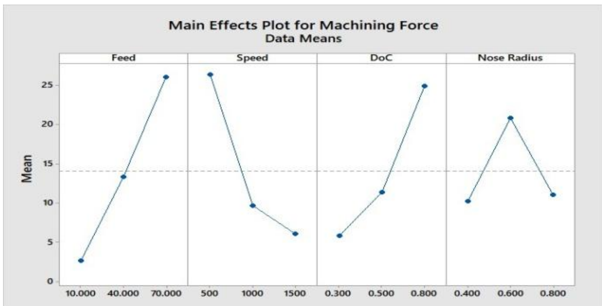

Figure 6: Main effect plot for machining force of AISI 52100 turning under L9 array

The change in speed from a value of 500 RPM to a value of 1500 RPM decreases the machining force from a value of 26.333 N to a value of 6.111 N. The change in depth of cut of the tool from 0.3 mm to 0.7 mm increases the value of machining force from 6.222 N to 24.889 N. The change in nose radius of the material from a value of 0.4 mm to 0.6 mm increases the machining force from a value of 10.222 N to a value of 20.833 N and the change in nose radius from 0.6 mm to 0.8 mm decreases the value of machining force from 20.833 N to 11.056 N.

5.Conclusions

An AISI 52100 was analyzed for its machinability under turning operations using the Taguchi technique. The Taguchi techniques facilitated the use of orthogonal arrays L9 are used to define the cutting parameters for the turning operations. The cutting parameters selected were Feed, speed, depth of cut and nose radius for turning operation. A statistical software was used to compare the main effect and interaction effect results obtained from the experimentation. The influences of cutting speed, feed rate, depth of cut and nose radius are investigated by Taguchi and ANOVA on the surface roughness and Material Removal Rate (MRR). Based on the results obtained, the following conclusions can be drawn:

1. Main effect plot for surface roughness during turning operation using L9 orthogonal array revealed that speed had the highest influence on surface roughness of the material.
2. Main effect plot for surface roughness during turning operation using L9 orthogonal array revealed that nose radius had the least influence on surface roughness of the material.
3. Main effect plot for material removal rate during turning operation using L9 orthogonal array revealed that feed rate had the highest influence on material removal rate of the material.
4. Main effect plot for material removal rate during turning operation using L9 orthogonal array revealed that nose radius had the least influence on material removal rate of the material.
5. Main effect plot for machining force during turning operation using L9 orthogonal array revealed that feed rate had the highest influence on machining force of the material.
6. Main effect plot for machining force during turning operation using L9 orthogonal array revealed that nose radius had the least influence on machining force of the material.

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