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Optimization of Cutting Parameters in Turning AISI 1020 MS by using Taguchi Method

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Abstract
In modern manufacturing, the selection of optimal cutting parameters is critical for improving product quality, maximizing production efficiency, and reducing machining costs. This investigation focuses on three fundamental machining variables cutting speed, feed rate, and depth of cut—as the primary control factors.
The experimental results will be analysed using the Signal-to-Noise (S/N) ratio to identify the optimal parameter combination for achieving minimum surface roughness and maximum material removal rate. Furthermore, Analysis of Variance (ANOVA) will be performed to determine the percentage contribution and statistical significance of each cutting parameter on the response variables.

Key Words: MRR, Cutting Parameters, ANOVA, Taguchi, signal to Noise Ratio (S/ N), L-9 orthogonal array

1. Introduction

1.1 Cutting Parameter Optimization

In the highly competitive manufacturing landscape, achieving optimal machining performance will be essential for improving product quality, reducing cycle times, and minimizing production costs. Optimization of cutting parameters will be crucial for controlling key performance indicators such as surface roughness, material removal rate (MRR), tool wear, and cutting forces.
Statistical techniques, such as the Taguchi method, will be employed to analyse multiple variables and their interactions with a drastically reduced number of experimental runs while maintaining statistical reliability.
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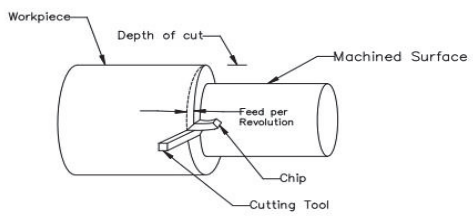

Fig.1 Drive in a metal cutting

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In all metal removal operations, the primary variables are cutting speed, feed rate, and depth of cut (DOC). The geometric configuration of these parameters during the turning process is illustrated in Figure 2.

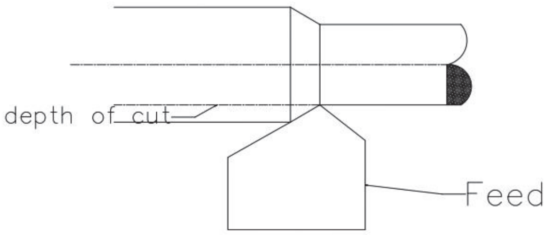

Fig 2 Turning of metal [2]

Contemporary manufacturing standards necessitate superior dimensional precision and high-quality surface finishes. Achieving such rigorous requirements through manual operations was exceptionally challenging, even for skilled technicians. Furthermore, manual processes are often time-intensive due to the constant adjustments required to avoid overcutting. The emergence of Computer Numerical Control (CNC) technology has revolutionized the industry by enabling automated machining with the flexibility to manage complex production tasks efficiently and will continue to play a vital role in future manufacturing advancements.

1.2 Taguchi Design

Genichi Taguchi, from Japan's Nippon Telegraph and Telephone Corporation, introduced a robust statistical framework for product development known as the Taguchi Methods. This approach utilizes specialized experimental designs based on Orthogonal Arrays—such as L9L_9L9, L18L{18}L18, L27L{27}L27, and L36L{36}L36—to identify the ideal configurations for control parameters.
Central to this methodology is the Signal-to-Noise (S/N) ratio, which functions as the objective function to minimize variability and achieve optimal performance. The procedural steps were illustrated in the flowchart and will be used to guide the experimental design and analysis in future studies shown in Figure 3.

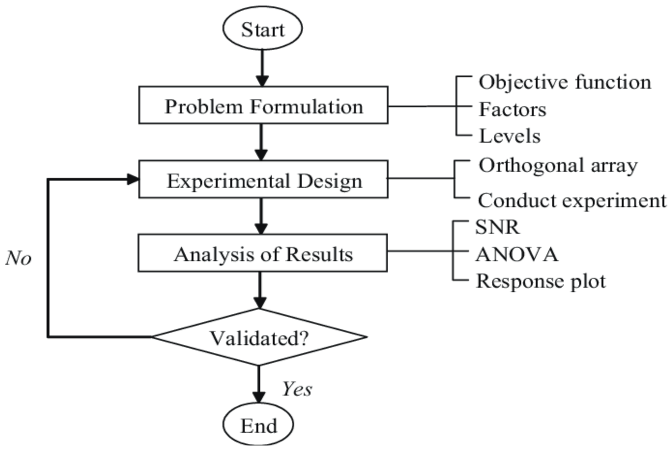

Fig 3 Flow Chart of Taguchi method

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2. Problem Statement

There is a critical need for a systematic and scientifically robust approach to optimize cutting parameters. The Taguchi method provides an effective solution by employing statistical design of experiments to identify optimal parameter settings with minimal experimental effort. This study aims to address the existing challenges by applying Taguchi methodology to optimize machining parameters for turning AISI 1020 mild steel, thereby improving surface quality, enhancing tool life, and increasing productivity.

3. Results and Discussion

Table 3.1: Variable factor of Experiment

Factor A (Spindle speed)		Factor B (Depth of Cut)		Factor C (Feed)	
Level	Value (rpm)	Level	Value (mm)	Level	Value (mm/rev)
A_1	250	B_1	0.5	C_1	0.086
A_2	400	B_2	1.25	C_2	0.093
A_3	600	B_3	2	C_3	0.1128

Table 3.2: Column Assignment of L9 OA

S.No.	Speed(A) rpm	Depth(B)mm	Feed(C) mm/rev
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 3.3: Variance of Means For surface Roughness

Factors	DOF	SS	V	F-RATIO	P%
Speed(A)	2	3.15352	3.15352	3.89	20.50%
DOC(B)	2	1.59945	1.59945	1.97	33.60%
Feed(C)	2	0.03573	0.03573	0.04	95.8%
Error	2	0.81101	0.81101		

3.2 Experiment Table for a Calculate Surface Roughness

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Table 3.4: Experiment Data

Trial No.	Surface Roughness (µm)			Average (µm)	S/N ratio dB
	R_1	R_2	R_3		
1	4.590	4.445	5.610	4.881	-13.770
2	4.390	3.656	5.510	4.518	-13.098
3	5.970	3.756	7.490	5.738	-15.175
4	2.720	3.221	3.410	3.117	-9.8747
5	3.450	4.090	4.330	3.956	-11.945
6	3.850	2.422	4.950	3.740	-11.457
7	3.010	3.390	3.780	3.393	-10.611
8	3.850	3.834	4.850	4.718	-13.475
9	5.340	2.973	6.670	4.994	-13.968

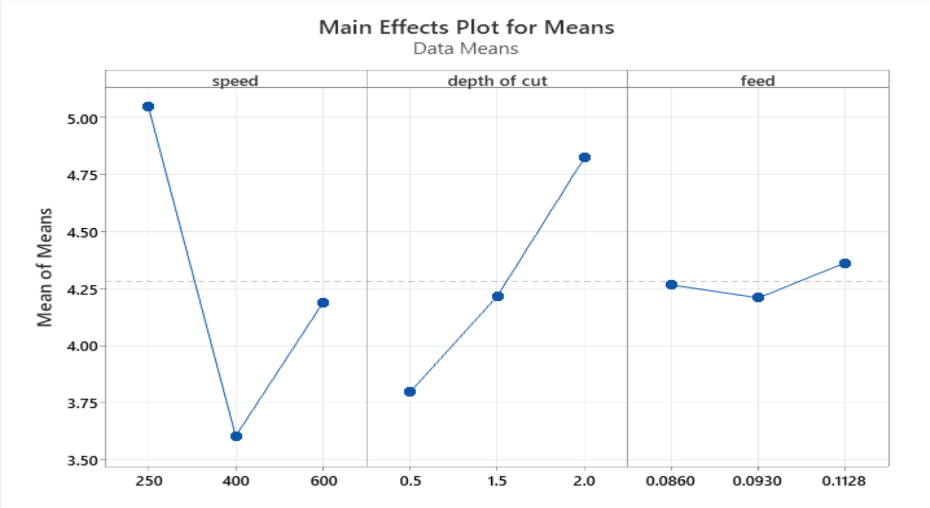

Fig 3.1 Main Effects Plot for Means for Surface Roughness

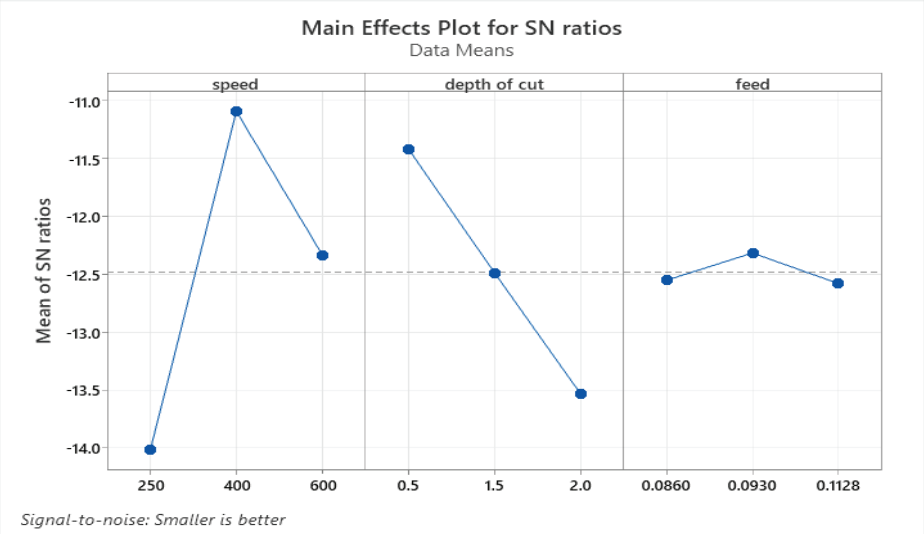

Fig 3.2 SN Ratios for Surface Roughness

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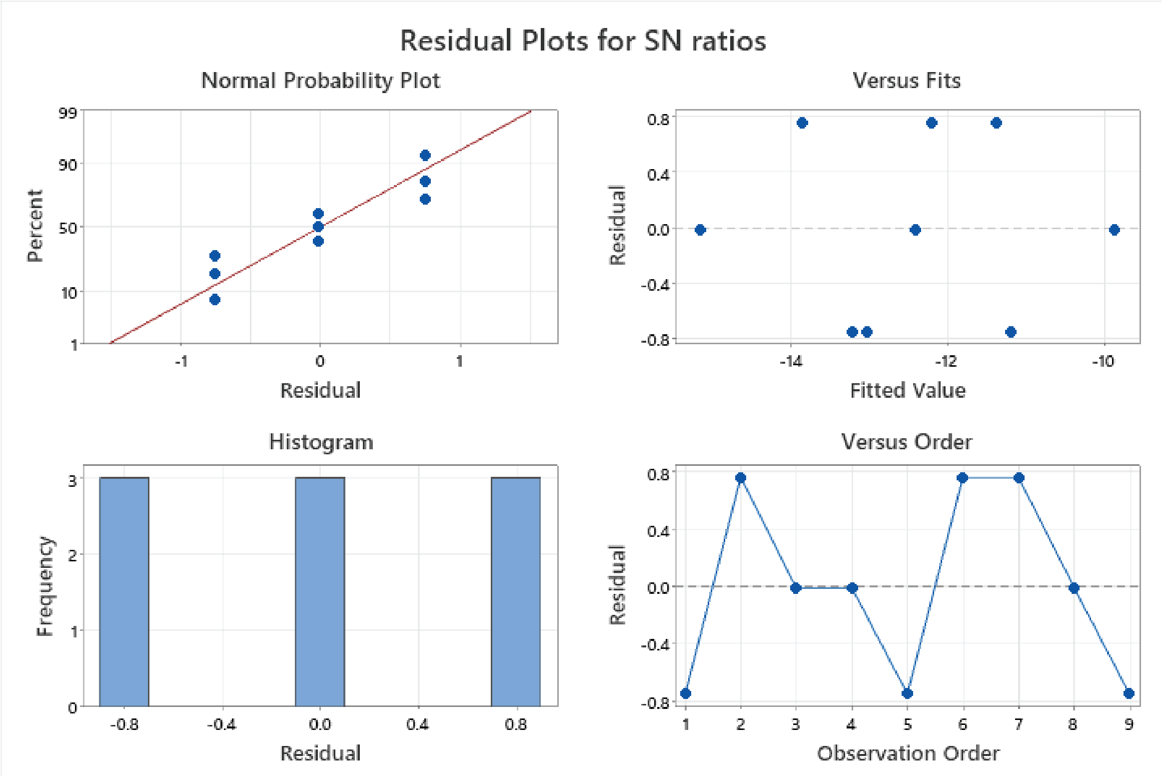

Fig 3.3 Residual Plots for Surface Roughness

Table 3.5: Result of the Confirmatory Experiment

Variable Factors			**Surface roughness, (µm)**			**Average, (µm)**	**Range with 95% CL**
Spindle Speed, rpm (Factor A)	**Depth of Cut, mm (Factor B)**	**Feed mm/rev (Factor C)**	**R_1**	**R_2**	**R_3**		
400	0.5	0.093	2.720	3.221	3.410	3.117	$1.388 \leq R_a(POP) \leq 3.329$ $0.418 \leq R_a\ (CE) \leq 4.299$

These parameters provided better machining performance and lower surface roughness.

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3.3 Manual Calculation of MRR in g/s:

Formula Used:

MRR = Mass Removed / Machining Time

Sample Manual Calculation Given:

- Initial weight = 1526 g
- Final weight= 1500 g
- Machining time= 180 sec

Mass removed = 1526 − 1500 = 26 g

MRR = 26 / 180

MRR 0.144 g/s

3.4 Experiment Table for a Calculate Material Removal Rate:

Table 3.6: Variance of Means for Material Removal Rate

Factors	DOF	SS	V	F-RATIO	P%
Speed(A)	2	0.10799	0.05399	3.16	24.00%
DOC(B)	2	0.05019	0.02509	1.47	40.50%
Feed(C)	2	0.04342	0.02171	1.27	44.00%
Error	2	0.03414	0.01707		
Total	8	0.23573			

Table 3.7: Experiment Data

SPEED(A)	DOC(B)	FEED(C)	MRR(g/sec)	S/N Ratio(n)
1	1	1	0.144	-16.8327
1	2	2	0.1699	-15.3961
1	3	3	0.185	-14.6565
2	1	2	0.29629	-10.5656
2	2	3	0.2620	-11.614
2	3	1	0.7111	-2.9626
3	1	3	0.3259	-9.7383
3	2	1	0.388	-8.2233
3	3	2	0.37037	-8.6195

Calculation of Material removal rate: Material removal rate (MRR) has been calculated from the difference of weight of work piece before and after experiment

Control parameter and their values:

- for low (speed, feed, depth of cut)
- for medium (speed, feed, depth of cut)
- for high (speed, feed, depth of cut)

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Table 3.8: Calculation of S/N Ratio

MRR	MRR^2	$1/MRR^2$	S/N Ratio(n)
0.144	0.020736	48.22530	-16.8327
0.1699	0.028866	34.642832	-15.3961
0.185	0.034225	29.218407	-14.6565
0.29629	0.087787	11.391208	-10.5656
0.2626	0.068958	14.501580	-11.6141
0.711	0.505521	1.978157	-2.9626
0.3259	0.106210	9.4153092	-9.7383
0.388	0.150544	6.6425762	-8.2233
0.3707	0.137418	7.277067	-8.6195

The analysis of variance (ANOVA) is another optimizing tool mentioned in the factorial design method to further optimize above parameters as discussed in section.

ANOVA is a statically based, objective decision-making tool for detecting any differences in average performance of groups of items tested. An ANOVA table consists of sum of squares, corresponding degree of freedom, the F-ratio corresponding to the ratios of two mean squares, and the contribution proportions from each of the control factors. These contribution proportions can be used to assess the importance of each factor for interested multiple performance characteristics (MPCs).

Signal-to-noise ratio is also called as SNR or S/N, is defined as the ratio of signal power to the noise power corrupting the signal. The Signal to Noise Ratio (SNR) is the defining factor when it comes to quality of measurement. A high SNR guarantees clear acquisitions with low distortions and artifacts caused by noise. The better your SNR, the better the signal stands out, the better the quality of your signals, and the better you ability to get the results you desire.

Table 3.9: Experiment Performed

Trial No.	Levels			
	(SPEED) A(rpm)	(DEPTH OF CUT) B(mm)	(FEED) C(mm/rev)	MRR(g/sec)
1	1	1	1	0.144
2	1	2	2	0.1699
3	1	3	3	0.185
4	2	1	2	0.2962
5	2	2	3	0.2626

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6	2	3	1	0.711
7	3	1	3	0.3259
8	3	2	1	0.388
9	3	3	2	0.3703

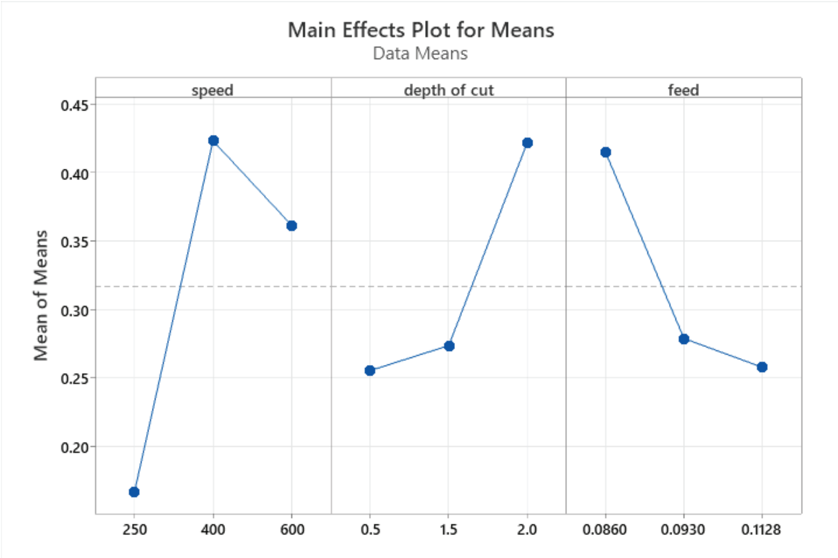

Fig 3.4 Main Effects Plot for Means For MRR

The graph shows that maximum value of material removal rate occurs at the level 2 of the experiment i.e. the optimum value is B2.

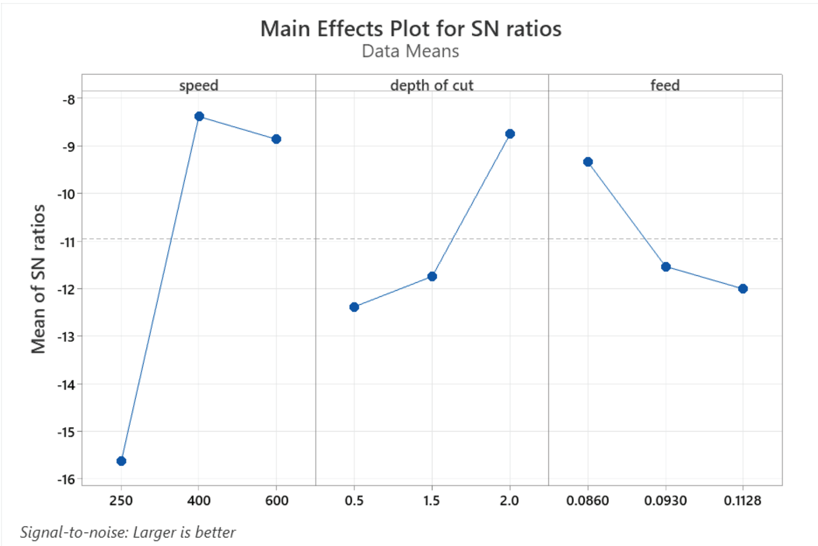

Fig 3.5 SN Ratio for MRR

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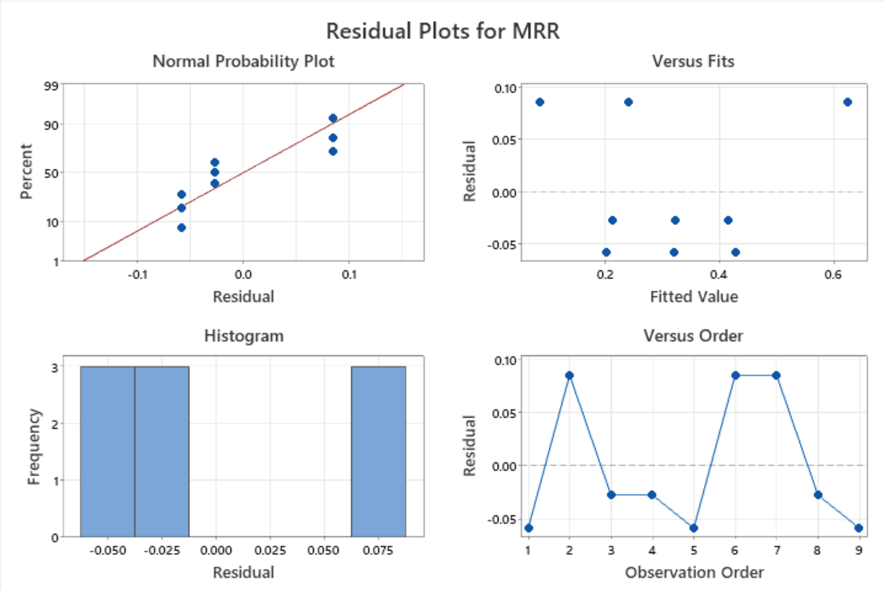

Fig 3.6 Residual Plots for MRR

Table 4.10: Result of Confirmatory Experiment

Performance characteristics	Optimal parameter level	Predicted parameter level
Material removal rate	A2,B3,C1	0.7111

These parameters provided better machining performance and higher Material Removal Rate.

4. CONCLUSIONS

Using the Taguchi method to optimize lathe machining of AISI 1020 is highly practical, as industries continuously seek to improve machining speed (higher MRR) without compromising surface quality or increasing tool wear.

This study successfully applied the Taguchi optimization method to investigate and improve CNC turning parameters for mild steel (AISI 1020).

Based on the Signal-to-Noise (S/N) ratio and ANOVA results, the following conclusions were drawn:

Surface Finish: Feed rate was identified as the most significant factor influencing surface roughness. A lower feed rate combined with a higher spindle speed was found to produce the best surface finish.

Productivity (MRR): Spindle speed and depth of cut were observed to be the most influential parameters in maximizing material removal rate (MRR).

Optimal Combination: The Taguchi L9 orthogonal array effectively determined an optimal combination of cutting speed, feed rate, and depth of cut, achieving a balance between high productivity and good surface quality.

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Industrial Impact: Replacing trial-and-error machining with this statistically optimized parameter setting can significantly reduce machining time, minimize tool wear, and improve the dimensional accuracy of AISI 1020 components in industrial applications.

4. FUTURE WORK AND SCOPE

The future scope of this methodology involves enhancing its intelligence, improving sustainability, and ensuring seamless integration with modern digital workflows.

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