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Performance Optimization in Mild Steel Shaping Operation Using Taguchi Design of Experments

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Abstract: *Performance optimization in machining processes is essential to improve product quality and productivity. This project focuses on optimizing shaping operations on mild steel using the Taguchi Design of Experiments (DOE) method. Key process parameters such as cutting speed, feed rate, and depth of cut are selected and varied systematically using an orthogonal array. The performance is evaluated based on surface roughness and material removal rate (MRR). Signal-to-Noise (S/N) ratio analysis is used to identify the optimal combination of parameters that minimizes surface roughness and maximizes MRR. The results demonstrate that the Taguchi method is an effective and efficient approach for improving machining performance with reduced experimental trials*

Keywords: Mildsteel,shaping operation,Taguchi method,design of experiments, surface roughness,material removal rate,optimization,signal to noise ratio

1.INTERODUCTION

Manufacturing industries play a vital role in the development of modern engineering systems. Among various manufacturing processes, machining operations are widely used to shape raw materials into desired dimensions and surface quality. One such important machining process is **shaping**, which is commonly used for producing flat surfaces, grooves, and slots.

Mild steel is one of the most commonly used engineering materials due to its excellent mechanical properties such as good strength, ductility, machinability, and cost-effectiveness.

However, achieving optimal machining performance while working on mild steel remains a challenge due to variations in process parameters.

Overview of Machining Processes

Machining is one of the most fundamental and widely used manufacturing processes in the field of mechanical engineering. It involves the removal of unwanted material from a workpiece in the form of chips using cutting tools to achieve the desired shape, size, and surface finish. Machining processes are essential in producing components with high dimensional accuracy and precision.

Common machining processes include turning, milling, drilling, grinding, and shaping. Each process has its own significance depending on the geometry and requirements of the component being manufactured. Among these, shaping is one of the traditional machining operations used for producing flat surfaces, slots, grooves, and keyways.

With the advancement of technology, modern industries demand higher productivity, better surface quality, and reduced manufacturing costs. Therefore, optimization of machining processes has become a critical area of research and development.

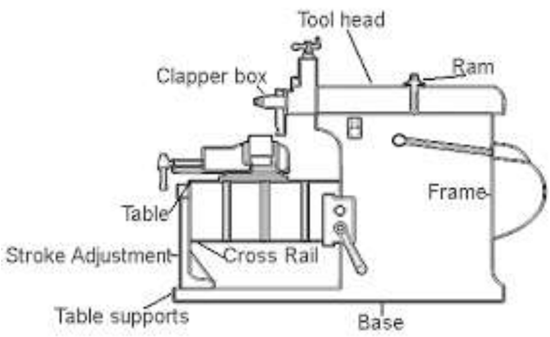

Fig no.1: **Shaping macine**

II. LITERATURE REVIEW

Machining processes such as turning, drilling, milling, and shaping are extensively used in manufacturing industries to achieve desired dimensions and surface quality. Optimization of machining parameters is essential to enhance productivity, reduce tool wear, and improve surface finish. Traditional optimization techniques are time-consuming and inefficient. Therefore, statistical methods like Design of Experiments (DOE) have gained importance for systematic analysis and optimization of process parameters [1].

Many researchers have extensively studied the optimization of machining parameters using the Taguchi method across various machining processes such as turning, drilling, milling, and shaping. The primary objective of these studies is to improve surface finish, reduce tool wear, and enhance material removal rate (MRR). It has been widely observed that machining performance is highly dependent on process parameters like cutting speed, feed rate, and depth of cut, and improper selection of these parameters leads to poor quality and inefficiency.

Optimization of Machining Parameters for shaping using Taguchi approch

Optimization of machining parameters in shaping operations is a critical aspect of manufacturing engineering, as it directly influences product quality, production rate, and overall machining cost. Shaping is a commonly used machining process for producing flat surfaces, slots, and grooves, particularly in materials like mild steel. However, the performance of the shaping process largely depends on the proper selection of process parameters such as cutting speed, feed rate, and depth of cut. If these parameters are not selected appropriately, it may result in poor surface finish, excessive tool wear, and low material removal rate (MRR). Therefore, there is a strong need for a systematic and scientific method to determine the optimal combination of these parameters.The Taguchi approach, a powerful statistical method for Design of Experiments (DOE), is widely used for optimizing machining processes. It simplifies the experimental design by using orthogonal arrays, which significantly reduce the number of experiments required while still providing reliable and accurate results. In this method, the machining parameters are selected as control factors, and each parameter is assigned different levels. Experiments are theconducted according to theChosen orthogonal array, such as L9 or L27, depending on the number of factors and levels involved.In the optimization of shaping operations, the key performance characteristics usually considered are surface roughness and material removal rate. Surface roughness is an important quality parameter that determines the smoothness and finish of the machined surface, while MRR indicates the productivity of the process. The Taguchi method uses Signal-to-Noise (S/N) ratio analysis to evaluate these performance characteristics. Depending on the objective, different types of S/N ratios are applied, such as “smaller-the-better” for surface roughness and “larger-the-better” for MRR. This analysis helps in identifying the parameter levels that minimize variability and improve performance under different conditions.After conducting the experiments and calculating the S/N ratios, the results are analyzed to determine the optimal levels of each machining parameter. Main effect plots are used to visualize the influence of each parameter on the performance characteristics. In addition, Analysis of Variance (ANOVA) is performed to identify the significance and contribution of each factor in the shaping process. This helps in understanding which parameter has the greatest effect on surface roughness and MRR, allowing engineers to focus on the most influential factors.The results of such optimization studies typically show that parameters like cutting speed and feed rate have a significant impact on both surface finish and productivity. By selecting the optimal combination of parameters, it is possible to achieve a smoother surface finish while maintaining a higher material removal rate. This leads to improved machining efficiency, reduced production time, and lower operational costs.In conclusion, the application of the Taguchi approach in optimizing machining parameters for shaping operations provides a systematic, efficient, and cost-effective method for improving process performance. It not only reduces the number of experimental trials but also enhances the quality and consistency of the machined product. This method is highly beneficial in industrial applications where productivity and quality are of utmost importance, making it a valuable tool in modern manufacturing engineering. Optimization of machining parameters in shaping operations is essential to achieve better surface quality and higher productivity. In this study, the Taguchi approach is applied to optimize key process parameters such as cutting speed, feed rate, and depth of cut during the machining of mild steel. The Taguchi Design of Experiments (DOE) method uses orthogonal arrays to systematically plan experiments with a reduced number of trials, ensuring efficient analysis. Performance characteristics like surface roughness and material removal rate (MRR) are evaluated to determine the effectiveness of each parameter setting. Signal-to-Noise (S/N) ratio analysis is employed to identify the optimal combination of machining parameters that minimizes variability and improves performance. The results indicate that the Taguchi method provides a simple, reliable, and cost-effective technique for optimizing shaping operations, leading to improved machining efficiency and product quality.

III.EXPERIMENTAL WORKS

The experimental work for optimizing machining parameters in shaping operations using the Taguchi approach is carried out in a systematic and structured manner to ensure accurate and reliable results. Initially, the objective of the experiment is clearly defined, which is to optimize process parameters such as cutting speed, feed rate, and depth of cut for improving surface roughness and material removal rate (MRR) during the machining of mild steel

Workpiece Material & cutting tool

Mild steel is selected as the workpiece material due to its wide industrial application and good machinability. Important machining parameters such as cutting speed, feed rate, and depth of cut are identified as control factors.

Design of Experiments (DOE)

Taguchi method is used with an appropriate orthogonal array (e.g., L9) to plan the experiments with different parameter levels. The shaping machine is prepared, and the workpiece is properly fixed. Cutting tool is aligned accurately. Machining is performed according to the combinations specified in the orthogonal array

Table 1: Input parameters for shaping machine

SI no	Parameters	Units	Level 1	Level 2	Level 3
1	Cutting speed	m/min	8.5	16	29
2	Feed rate	mm/stroke	0.2	0.4	0.6
3	Depth of cut	mm	0.5	1.0	1.5

Measuring Instruments

In the present experimental study, accurate measurement of machining performance parameters is essential to evaluate the effect of process variables and to achieve reliable optimization using the Taguchi method. Therefore, suitable measuring instruments were used to ensure precise and consistent data collection. The primary parameter measured in this study is surface roughness, which is a key indicator of machining quality. In addition to surface roughness, dimensional accuracy of the workpiece was also verified using standard measuring tools.

1.Surface Roughness Tester:

Used to the Mitutoyo surface finish (Ra,Rc,Rz value)

In this experimental study, the surface quality of the machined mild steel specimens was evaluated using a Mitutoyo surface roughness tester, which is a highly precise and widely used instrument in machining and quality control applications. The instrument measures different surface roughness parameters such as Ra, Rc, and Rz, which provide detailed information about the surface texture and finish of the workpiece. These parameters are essential for assessing machining performance and for optimizing process parameters using the Taguchi method.

Figno. 2 Mitutoyo surface finish

Ra (Arithmetic Average Roughness)

The most commonly used parameter is Ra (Arithmetic Average Roughness), which represents the average of the absolute deviations of the surface profile from the mean line over a specified sampling length. It is expressed in micrometers (µm) and provides a general indication of the surface finish. Lower values of Ra indicate a smoother surface, while higher values indicate a rougher surface. In most machining optimization studies, including this project, Ra is considered the primary response parameter, and the objective is to minimize its value using the “smaller is better” criterion.

Experimental planning

Experimental planning is an important step in optimizing machining parameters for shaping operations using the Taguchi approach. It involves systematically designing experiments to study the effect of different process parameters on performance characteristics. In this project, key machining parameters such as cutting speed, feed rate, and depth of cut are selected as control factors, and each parameter is assigned specific levels based on machine capability and practical limits.

IV. EXPERIMENTAL RESULT AND DISUCSSION

Effect of process parameters on material removal rate

The material removal rate (MRR) in shaping operations is significantly influenced by key process parameters such as cutting speed, feed rate, and depth of cut. Among these, depth of cut has a direct and major impact on MRR, as increasing the depth of cut increases the volume of material removed per stroke. Similarly, feed rate plays a crucial role; higher feed rates result in greater material removal because more material is cut during each pass of the tool.

Table 2. S/n ratio value for Material removal rate value

SI no	Cutting speed m/min	Feed rate mm/stroke	Depth of cut mm	MRR mm^3/min	S/N ratio (dB)
1	8.5	0.2	0.5	835	58.43
2	8.5	0.4	1.0	3340	70.47
3	8.5	0.6	1.5	7515	77.51
4	16	0.2	1.0	3173	70.02
5	16	0.4	1.5	9519	79.57
6	16	0.6	0.5	4760	73.55
7	29	0.2	1.5	8642	78.73
8	29	0.4	0.5	5762	75.21
9	29	0.6	1.0	17285	84.75

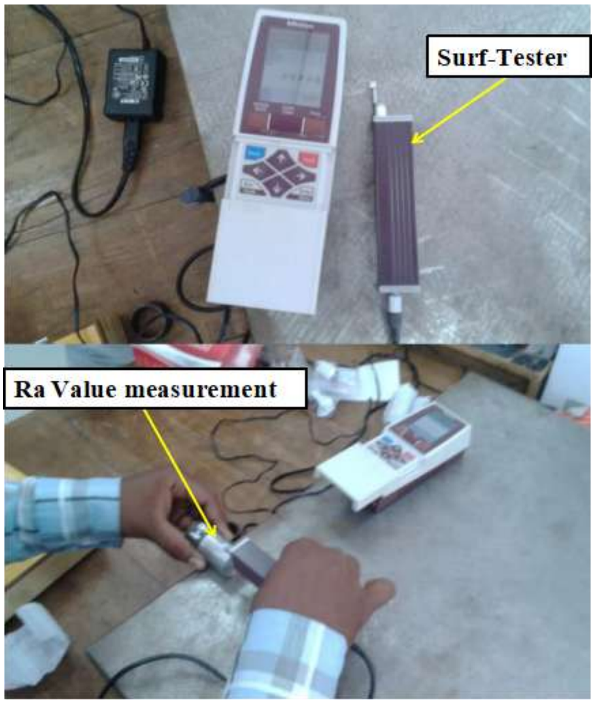

***Fig.2*: Set-up for Surface roughness (Ra) value Measurement**

Selection of optimal levels

In order to study the significance of the process variables towards surface roughness, analysis of variance (ANOVA) was performed. From these tables, it is clear that speed and depth of cut significantly affect both the surface roughness value.

The ranks and the delta values show that speed have the greatest effect on surface roughness and are followed by depth of cut. As surface roughness is the "smaller is better" type quality characteristic, it can be seen from Figure 4 that the third level of speed(A3) and second level of depth of cut (B2) provide best value of surface roughness. The S/N data analysis suggests the same levels of the variables (A3 and B2) as the best levels.

Table 3.Calculation range of MRR

LEVEL	CUTTING SPEED (N)	FEED RATE (F)	DEPTH OF CUT (D)
1	68.803	69.06	69.06
2	74.38	75.08	75.08
3	79.56	78.60	78.60
RANGE	10.57	9.54	9.54
RANK	1	2	3

Effect of process parameters on tool tip temperature

In order to see the effect of process parameters on the Tool tip temperature, experiments were conducted using L9 OA (Table 2). The experimental data and S/N ratios is given in Table 3**.** According to response table 6, graphs were generated shown in Figure 5 which shows that the Tool tip temperature increases with the increase of speed and depth of cut while decreases when both value are at level one.

Table 4.Degree of freedom

source	DOF
N	3-1=2
F	2
D	2
Error	9-1-6=2
Total	8

RESULT OF MRR :

Cutting Speed has highest effect (24.6%)

Depth of Cut and Feed Rate have equal influence

High error (42.9%) indicates:

○ Experimental noise OR
Interaction effects not considered

Table 5.ANOVA TABLE

FACTOR	SS	DOF	MS	F	CONTRIBUTION
Cutting speed	187.99	2	93.99	0.57	**24.6%**
Depth of cut	124.13	2	62.07	0.38	**16.2%**
Feed rate	124.13	2	62.07	0.38	**16.2%**
Error	327.65	2	163.83	-	**42.9%**
Total	763.90	8	-	-	**100%**

Effect of process parameters on surface roughness (Ra)

Effect of process parameters on surface roughness In order to see the effect of process parameters on the MRR, experiments were conducted using L9 OA (Table 2). The experimental data and S/N ratios is given in Table 3. According to response table 4, graphs were generated shown in Figure 3 which shows that the surface roughness decreases with the increase of speed and also increases in depth of cut there is decrement in surface roughness.

Table 6. S/n ratio value for surfaceroughness arithmetic mean

SI no	speed (m/min)	Feed rate (mm/stroke)	Depthof cut (mm)	Ra Trail 1	Ra Trail2	average	S/Nratio (dB)
1	8.5	0.2	0.5	3.424	11.804	7.614	-17.63
2	8.5	0.4	1.0	7.890	4.931	6.410	-16.13
3	8.5	0.6	1.5	1.333	1.636	1.484	-3.428
4	16	0.2	1.0	1.393	1.732	1.562	-3.873
5	16	0.4	1.5	6.423	2.972	4.697	-13.43
6	16	0.6	0.5	3.250	2.110	2.680	-8.562
7	29	0.2	1.5	2.678	2.925	2.801	-8.946
8	29	0.4	0.5	3.212	1.865	2.538	-8.089
9	29	0.6	1.0	2.555	1.268	1.911	-5.625

surface roughness (Ra) arthematic mean

Surface roughness, commonly represented by the arithmetic mean roughness (Ra), is an important parameter that indicates the quality of a machined surface. Ra is defined as the average of the absolute deviations of the surface profile from the mean line over a specified sampling length. In shaping operations, Ra is significantly affected by process parameters such as cutting speed, feed rate, and depth of cut. An increase in feed rate generally leads to higher Ra values, resulting in a rougher surface finish due to larger tool marks.

Table 7 : calculation of range for surface roughness(Ra)

LEVEL	CUTTING SPEED (N)	FEED RATE (F)	DEPTH OF CUT (D)
1	-12.496	-10.149	-11.407
2	-8.621	-12.549	-8.542
3	-7.553	-5.871	-8.601
RANGE	4.943	6.678	2.865
RANK	2	3	1

Degree of freedom in surface roughness (ra)

In the Taguchi method, the degree of freedom (DOF) represents the number of independent comparisons that can be made to analyze the effect of process parameters on a response such as surface roughness (Ra). It is an important concept used while selecting an appropriate orthogonal array and performing analysis like ANOVA.

For machining parameters, the degree of freedom is calculated based on the number of factors and their levels. The formula for DOF of a factor is:

DOF = Number of levels – 1

Table 8. Degree of freedom

source	DOF
N	3-1=2
F	2
D	2
Error	9-1-6=2
Total	8

RESULT OF SURFACE ROUGHNESS (Ra)

Feed rate has the highest influence on surface roughness.

Cutting speed is moderately significant.

Depth of cut has the least effect.

High error % suggests possible experimental noise or missing interaction effect

Table 9.ANOVA TABLE

FACTOR	SS	DOF	MS	F	CONTRIBUTION
Cutting speed	38.837	2	19.419	0.439	**18.30%**
Depth of cut	68.657	2	34.329	0.776	**32.35%**
Feed rate	16.287	2	8.144	0.184	**7.67%**
Error	88.426	2	44.213	-	**41.68%**
Total	212.207	8	-	-	100

V.CONCLUSION

This paper provided a comprehensive understanding of the shaping machine and its operational aspects, which are essential for conducting machining experiments. The working principle of the shaping machine, based on the reciprocating motion of the cutting tool, was explained in detail. Various types of shaping machines, including horizontal, vertical (slotter), crank type, geared type, and hydraulic shaping machines, were discussed along with their specific features and applications. The construction and functions of major components such as the ram, tool head, table, and feed mechanism were also described.

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