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EXPERIMENTAL, STATISTICAL INVESTIGATIONS AND OPTIMIZATION OF CUTTING PARAMETERS OF STEEL SM45C DURING MACHINING USING TAGUCHI METHOD

[1]Vishal A. Yewalikar, [2]Vaibhav M. Bhalerao, [3]Niketan B. Godse, [4]Parth G. Naik, [5]Rutik M. Rathod
[1]Assistant Professor, [2]Student, [3]Student, [4]Student, [5]Student
Department of Mechanical Engineering
P.E.S. Modern College of Engineering, Pune, Maharashtra, India

Abstract: Every manufacturing industry aims at producing a large number of products within relatively lesser time. These days one of the most important machining processes in industries is turning. Turning is affected by many factors such as the cutting speed, feed rate, depth of cut and geometry of cutting tool etc., which are input parameters in this project work. The desired product of dimensional accuracy and less surface roughness is influenced by cutting force and tool vibration which are the responses and the functions of these input parameters. In this project turning of Steel SM45C work piece sample of propeller shaft and carbide insert tool will be performed on lathe machine. SM45C Steel is used as the work piece material for carrying out the experimentation to optimize the Surface Roughness and Material Removal Rate. The bars will be use of diameter 20 mm and length 100 mm. Experiment have been carried out based on L9 standard orthogonal array design with three process parameters namely Cutting Speed, Feed, Depth of Cut for surface roughness and Material removal rate (MRR). The signal to noise ratio and analysis of variance were employed to study the performance characteristics in turning operation. The data was compiled into MINITAB 21 for analysis. The relationship between the machining parameters and the response variables (Surface Roughness and MRR) were modeled and analyzed using the Taguchi method. It is predicted that Taguchi method is a good method for optimization of various machining parameters as it reduces number of experiments. The results indicate the optimum values of the input factors and the results are conformed by a confirmatory test. Analysis of Variance (ANOVA) was used to investigate the significance of these parameters on the response variables.

Index Terms **-** Taguchi method, Orthogonal array, S/N Ratio, Process parameter, Surface roughness, Material Removal Rate (MRR), ANOVA (Analysis of Variance).

I. INTRODUCTION

In modern industry, technological advancements require engineers to achieve good surface finish, economic production, minimal cutting tool wear, and optimized resource use. A crucial process in mechanical engineering is metal cutting, defined as the removal of chips to achieve the desired product shape, size, and surface roughness. Turning, a widely used metal cutting method, involves a single point cutting tool removing metal by feeding parallel to the axis of rotation. Automated lathes, which require minimal labor or supervision, commonly perform turning.

Selecting machining parameters for turning is essential for high performance, which includes good machinability, better surface finish, lower tool wear, higher material removal rate, and faster production. Surface finish, measured by surface roughness, is an index of product quality, influencing strength properties (e.g., corrosion resistance, fatigue life) and functional behaviors (e.g., friction, heat transmission).

Optimizing cutting parameters is crucial to minimize surface roughness and improve tool life, which affects product quality and costs.

Factors influencing material removal rate and surface roughness include machining parameters (cutting speed, feed, depth of cut), tool material, work material, and tool geometry. Optimization is needed to achieve desired results, which involves getting the best outcomes within resource constraints. Statistical design of experiments, such as Response Surface Methodology (RSM), Taguchi method, and factorial designs, are extensively used in optimization, replacing the costlier and time-consuming one-factor-at-a-time approach.

The Taguchi method improves quality by reducing variation through offline or online quality control. Offline control enhances process quality, while online control maintains design conformance. The method ensures product performance despite noise and is quickly and easily applied, making it popular in manufacturing. Surface roughness and cutting force are critical machining parameters, with cutting force influencing power calculation, dimensional accuracy, work-piece deformation, and chip formation. Optimization processes help achieve required surface roughness and overall process quality.

II. LITERATURE REVIEW

[1] "Application Of Taguchi Method For Optimization Of Process Parameters In Improving The Surface Roughness Of Lathe Facing Operation" by Srinivas Athreya, Dr Y.D.Venkatesh-Taguchi Method is a statistical approach to optimize the process parameters and improve the quality of components that are manufactured. The objective of this study is to illustrate the procedure adopted in using Taguchi Method to a lathe facing operation. The orthogonal array, signal-to-noise ratio, and the analysis of variance are employed to study the performance characteristics on facing operation. In this analysis, three factors namely speed; feed and depth of cut were considered. Accordingly, a suitable orthogonal array was selected and experiments were conducted. After conducting the experiments the surface roughness was measured and Signal to Noise ratio was calculated. With the help of graphs, optimum parameter values were obtained and the confirmation experiments were carried out. These results were compared with the results of full factorial method.

[2] "Application of Taguchi Method for Optimizing Turning Process by the effects of Machining Parameters" by Krishankant, Jatin Taneja, Mohit Bector, Rajesh Kumar - This paper reports on an optimization of turning process by the effects of machining parameters applying Taguchi methods to improve the quality of manufactured goods, and engineering development of designs for studying variation. EN24 steel is used as the work piece material for carrying out the experimentation to optimize the Material Removal Rate. The bars used are of diameter 44mm and length 60mm. There are three machining parameters i.e. Spindle speed, Feed rate, Depth of cut. Different experiments are done by varying one parameter and keeping other two fixed so maximum value of each parameter was obtained. Operating range is found by experimenting with top spindle speed and taking the lower levels of other parameters. Taguchi orthogonal array is designed with three levels of turning parameters with the help of software Minitab 15. In the first run nine experiments are performed and material removal rate (MRR) is calculated. When experiments are repeated in second run adain MRR is calculated. Taguchi method stresses the importance of studying the response variation using the signal–to–noise (S/N) ratio, resulting in minimization of quality characteristic variation due to uncontrollable parameter. The metal removal rate was considered as the quality characteristic with the concept of "the larger-the-better". The S/N ratio for the larger-the-better Where n is the number of measurements in a trial/row, in this case, n=1 and y is the measured value in a run/row. The S/N ratio values are calculated by taking into consideration with the help of software Minitab 15. The MRR values measured from the experiments and their optimum value for maximum material removal rate. Every day scientists are developing new materials and for each new material, we need economical and efficient machining. It is also predicted that Taguchi method is a good method for optimization of various machining parameters as it reduces the number of experiments. From the literature survey, it can be seen that there is no work done on EN24 steel. So in this project the turning of EN24 steel is done in order to optimize the turning process parameters for maximizing the material removal rate.

[3] "A Review on Optimization of Process Parameters for Surface Roughness and Material Removal Rate for SS 410 Material During Turning Operation" by Jitendra Thakkar , Mitesh I Patel - In machining operations, the extents of significant influence of the process parameters like speed, feed, and depth of cut are different for different responses. Therefore, optimization of surface roughness is a multi-factor, multi-objective optimization problem. Therefore, to solve such a multi objective optimization problem, it is felt Necessary to identify the optimal parametric combination, following which all objectives could be optimized simultaneously. In this context, it is essential to convert all the objective functions into an equivalent single objective function or overall representative function to meet desired multi-quality features

of the machined surface. The required multi-quality features may or may not be conflicting in nature. The representative single objective function, thus calculated, would be optimized finally. All experiment conduct on CNC turning machine on SS410 material. In the present work, Design of Experiment (DOE) with full factorial design has been explored to produce 27 specimens on SS410 by straight turning operation. Material removal rate (MRR)
Will be calculated from MRR equation and software available for it and then compare it. Collected data related to surface roughness have been utilized for optimization.

[4] "Optimization of Different Machining Parameters of En24 Alloy Steel In CNC Turning by Use of Taguchi Method" byMahendra Korat, Neeraj Agarwal - The present paper outlines an experimental study to optimize the effects of cutting parameters on surface finish and MRR of EN24/AISI4340 work material by employing Taguchi techniques. The orthogonal array, signal to noise ratio and analysis of variance were employed to study the performance characteristics in turning operation. Five parameters were chosen as process variables: Speed, Feed, Depth of cut, Nose radius, Cutting environment (wet and dry). The experimentation plan is designed using Taguchi's L18 Orthogonal Array (OA) and Minitab 16 statistical software is used. Optimal cutting parameters for, minimum surface roughness (SR) and maximum material removal rate were obtained. Thus, it is possible to increase machine utilization and decrease production cost in an automated manufacturing environment.

III. EXPERIMENTAL SETUP -

Selection of Material:

SM45C, medium carbon steel, is widely used in the industrial sector for producing machine parts like gears and cranks, and as cold-work die steel. It's also used to make automotive drive shafts, propeller shafts, and other structural parts. SM45C is SAE1045 grade steel with a carbon percentage of approximately 0.45%. It has good mechanical properties and is often used for structural parts that can support stress alternation, such as bolts, connecting rods, and wheel gears. SM45C is also the most common material for shaft parts.

Chemical Composition of SM45C:

Table 1: Chemical Composition of SM45C (wt. %)

Material	Chemical Composition (wt. %)									
	C	Si	Mo	Cr	Mn	Ni	S	P	Cu	Fe
SM45C	0.410	0.250	-	0.020	0.700	0.030	0.050	0.030	-	Bal.

Material Properties for SM45C:

Table 2: Material Properties for SM45C

Material	Young's Modulus (Gpa)	Yield Strength (Mpa)	UTS (Mpa)	Density (g/cm^3)
SM45C	569	343	207	7.7

Lathe Machine:
Medium duty lathe machine is used for carried out turning operation.

Figure 1: Conventional Lathe Machine

Turning Operation:

A common method used for create specific dimensions of product is turning. In machining operation removes material from cylindrical workpiece. It is used for reduce diameter of workpiece usually to a specified or different diameters. It is performed on external surface of workpiece. In this machining operationwork piece is rotating, single point cutting tool is used to remove material and Cutting tool insert parallel to the axis of workpiece material.

Taguchi Method:

Genichi Taguchi, he was born in Japan 1924, basically an electrical engineer and worked during nineteen 1950's to improve Japan's post-World War 2 telephone communication system. And he is the father of Taguchi method, typically robust design. So, you all understand the meaning of robustness, less sensitive to the other factors, external factors, and performs to the targeted value gives the desirable performance. And this is something we call as robustness, so Taguchi emphasize on robustness of the design, and that is where he brought his concept in the domain of design of experiment.

Design of experiment – Taguchi Approach

To make the DOE easier and more attractive to research, the following technique are used:

Standardized DOE – For designing experiments, Taguchi utilized a special set of tables, called orthogonal arrays (OAs), which represent the smallest fractional factorials and are used for most common experiment designs.

Signal-to-noise (S/N) analysis – For analysis of results from multiple-sample tests, use of signal-to- noise ratios

instead of the results makes the analysis of DOE results much easier. In addition, the logarithmic transformation of the results in terms of S/N ratios empowers the prediction of improvement in performance from the analysis.

Surface Roughness Instrument:

Talysurf is a device used for measurement of surface roughness which known as Portable profilometer (Taylor Hobson Surtronic 3+). This is a stylus based instrument which is based on the principle of a probe running across the surface to measure the variation of height as a function of distance.

Minitab Software: Minitab is a software product that helps you to analyses the data. This is designed essentially for the Six Sigma professionals. It provides a simple, effective way to input the statistical data, manipulate that data, identify trends and patterns, and then extrapolate answers to the current issues. This is most widely used software for the business of all sizes - small, medium and large. Minitab provides a quick, effective solution for the level of analysis required in most of the Six Sigma projects.

Controllable Cutting Parameter and Orthogonal Array:

Following controllable cutting parameters and their levels are considered for Taguchi orthogonal array. These cutting parameters are putted in Minitab software to create orthogonal array.

Table 4: Controllable Cutting Parameter and Their Levels

Sr. No.	Cutting Parameters	Levels		
		Level 1	Level 2	Level 3
1	Spindle Speed (rpm)	244	314	424
2	Feed Rate (mm/Rev)	0.10	0.25	0.50
3	Depth of Cut (mm)	1.0	1.5	2.0

Figure 2: Turning Operation of SM45C Steel

Figure 3: Working piece after Machining

Table 4: Taguchi Orthogonal Array

Sr. No.	Spindle Speed (rpm)	Feed Rate (mm/rev)	Depth of Cut (mm)
1	244	0.10	1.0
2	244	0.25	1.5
3	244	0.50	2.0
4	314	0.10	1.5
5	314	0.25	2.0
6	314	0.50	1.0
7	424	0.10	2.0
8	424	0.25	1.5
9	424	0.50	1.0

IV. RESULT AND ANALYSIS –

Table 5: S/N ratio and Mean Values for MRR

Exp. No.	MRR (mm^3/min)	S/N ratio for MRR	MEAN for MRR
1	1533.1	63.7114	1533.1
2	5749.1	75.1920	5749.1
3	15331.0	83.7114	15331.0
4	2959.4	69.4244	2959.4
5	9864.6	79.8816	9864.6
6	9864.6	79.8816	9864.6
7	5328.1	74.5315	5328.1
8	6660.2	76.4697	6660.2
9	19980.5	86.0121	19980.5

Table 6: S/N ratio and Mean Values for SR

Exp. No.	SR (μm)	S/N ratio for SR	MEAN for SR
1	0.3	10.4576	0.3
2	1.0	20	1.0
3	0.2	13.9794	0.2
4	8.0	1.93882	8.0
5	2	-6.020	2
6	3.5	-10.8814	3.5
7	3.5	-10.8814	3.5
8	1.5	-3.52118	1.5
9	5.5	-14.8073	5.5

S/N ratios for Material Removal Rate:

Larger is better

Table 7: Response Table for S/N ratios (MRR)

Level	Spindle Speed	Feed rate	Depth of Cut
1	74.20	69.22	73.35
2	76.40	77.18	76.68
3	79.00	83.20	79.37
Delta	4.80	13.98	6.02
Rank	3	1	2

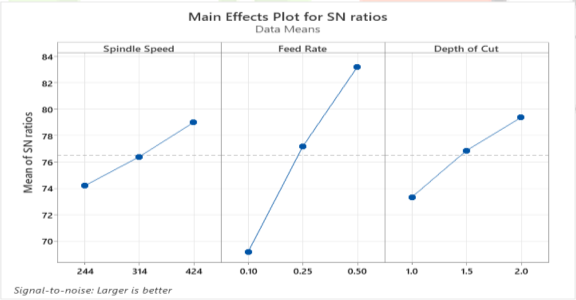

Figure 4: S/N ratios for MRR (Larger is better)

S/N ratios for Surface Roughness:

Smaller is better

Table 8: Response Table for S/N ratios (SR)

Level	Spindle Speed	Feed rate	Depth of Cut
1	8.1457	-6.16	-1.31
2	-11.65	-3.18	-10.9
3	-9.736	-3.90	-0.97
Delta	19.800	2.98	9.982
Rank	1	3	2

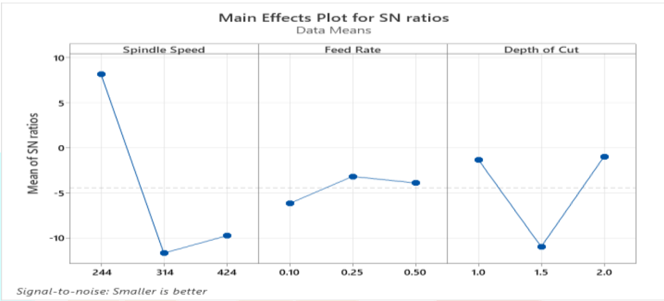

Figure 5: S/N ratios for SR (Smaller is better)

V. CONCLUSIONS

From result it is concluded that Taguchi method requires less data to find the optimum condition .Therefore it is recommended to use Taguchi method if the experimental run is time consuming and costly. So for turning a Steel SM45C work piece sample of propeller shaft Taguchi method is used. By Taguchi optimization method we calculate optimization parameters for turning of SM45C work piece. It is seen that Spindle speed 244 rpm, Feed Rate 0.50 mm/rev and Depth of Cut 2.0 mm are optimize parameters for Surface Roughness and for Material Removal Rate. By ANOVA (Analysis of Variance), we find influenced parameters for Surface Roughness and Spindle speed 424 rpm, Feed Rate 0.50 mm/rev and Depth of Cut 1.0 mm are optimize parameters for Material Removal Rate are Spindle speed and Feed rate respectively. ANOVA is used to know the percentage contribution of control process parameters such as Spindle speed is 74.53% on Surface Roughness and Feed Rate is 76.72 % on the Material Removal Rate. Optimization of cutting parameters by using this approach which will useful for the industry to optimize the machine performance and reduce wastage.

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