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Taguchi Optimization of Cutting Parameters for Surface Roughness and Material Removal Rate in Turning Operation

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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. 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 ® 17 for analysis. The relationship between the machining parameters and the response variables (surface roughness and MRR) were modeled and analyzed using the Taguchi method. Analysis of Variance (ANOVA) was used to investigate the significance of these parameters on the response variables, and to determine a regression equation for the response variables with the machining parameters as the independent variables, with the help of a quadratic model. Main effects and interaction plots from the ANOVA were obtained.

keywords: ANOVA, Taguchi Method, MRR.

INTRODUCTION

In the modern industry technology is advancing. For that engineers should be ready to achieve product of good surface finish, economic production, less wear of cutting tool with optimizing the use of resources. One of the most important manufacturing processes in mechanical engineering is metal cutting which is defined as metal removal of chips from job to achieve the desired product of appropriate shape, size and surface roughness [2]. In metal cutting most regularly used method is turning in which a single point cutting tool does metal removal by giving feed in a parallel direction to the axis of rotation. Turning can be done in an automated lathe machine which does not require more labor or frequent supervision by operator. The turning operation is a basic metal machining operation that is used widely in industries dealing with metal cutting. The selection of machining parameters for a turning operation is a very important task in order to accomplish high performance. By high performance, we mean good machinability, better surface finish, lesser rate of tool wear, higher material removal rate, faster rate of production etc.[1] The surface finish of a product is usually measured in terms of a parameter known as surface roughness. It is considered as an index of product quality. Better surface finish can bring about improved strength properties such as resistance to corrosion, resistance to temperature, and higher fatigue life of the machined surface. In addition to strength properties, surface finish can affect the functional behavior of machined parts too, as in friction, light reflective properties, heat transmission, ability of distributing and holding a lubricant etc.

Surface finish also affects production costs. For the aforesaid reasons, the minimization of the surface roughness is essential which in turn can be achieved by optimizing some of the cutting parameters. Tool wear is an inherent phenomenon in every traditional cutting operation. Researchers strive towards elimination or minimization of tool wear as tool wear affects product quality as well as production costs. In order to improve tool life, extensive studies on the tool wear characteristics have to be conducted. Some of the factors that affect tool wear and surface roughness are machining parameters like cutting speed, feed, depth of cut etc., tool material and its properties, work material and its properties and tool geometry. Minimal changes in the above mentioned factors may bring about significant changes in the product quality and tool life .In order to achieve desired results, optimization is needed. Optimization is the science of getting most excellent results subjected to several resource constraints. In the present world scenario, optimization is of utmost importance for organizations and researchers to meet the growing demand for improved product quality along with lesser production costs and faster rates of production. Statistical design of experiments is used quite extensively in optimization processes. Statistical design of experiments refers to the process of planning the experiments so that appropriate data can be analyzed by statistical methods, resulting in valid and objective conclusions.[3] Methods of design such as Response Surface Methodology (RSM), Taguchi method, factorial designs etc., find unbound use nowadays replacing the erstwhile one factor at a time experimental approach which more costly as well as time-consuming . Neseli et. al used RSM method and Nose radius, approach angle and rake angle as the input variables and found that the nose radius has the most significant effect on surface roughness. Nanavati and Makadia used feed, cutting speed and tool nose radius as predictors in the RSM method and determined that feed was the most significant factor affecting the surface roughness followed by the tool nose radius. Yang and Tarng used the Taguchi method to find the optimal cutting parameters[2]. A study conducted by Bouacha, showed that feed rate was the most influential parameter in determining surface finish of a product followed by the cutting speed[5]. Halim found that tool wear is most significantly affected by the depth of cut while other factors were seemingly insignificant.[14] The present study uses cutting speed, feed, and depth of cut as the machining parameters and the objective is to optimize these parameters so as to find the minimum surface roughness and tool wear.

TURNING

The turning operation is a basic metal machining operation that is used widely in industries dealing with metal cutting. In a turning operation, a high-precision single point cutting tool is rigidly held in a tool post and is fed past a rotating work piece in a direction parallel to the axis of rotation of the work piece, at a constant rate, and unwanted material is removed in the form of chips giving rise to a cylindrical or more complex profile. This operation is carried out in a Lathe Machine either manually under an operator's supervision, or by a controlling computer program. There are two types of motion in a turning operation. One is the cutting motion which is the circular motion of the work and the other is the feed motion which is the linear motion given to the tool. The basic turning operation with the motions involved is shown in Fig 1 and Fig 2.

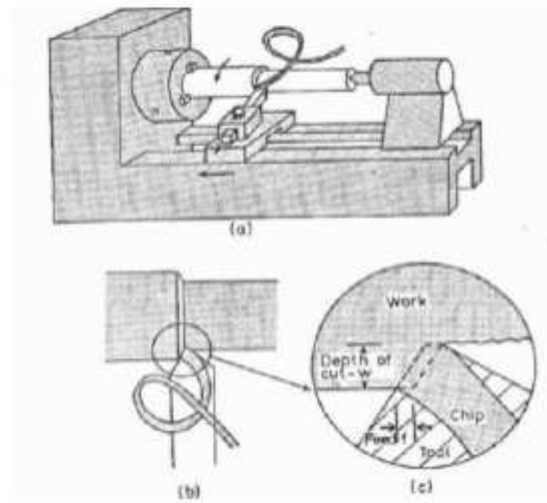

Fig 1: Basic turning operation in Lathe

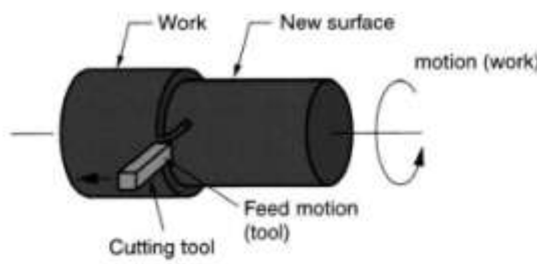

Fig 2: Motions in turning operation

METHODOLOGY

Fig.3 Process methodology chart.

EXPERIMENTAL

High-performance LT Series CNC lathes deliver the ultimate in rigidity with 6-inch, 8-inch and 10-inch chuck sizes. The full-enclosure, FC30 Meehanite cast-iron design features a 30 degree slant bed for excellent support to the spindle head, turret and tailstock with low gravity. High-precision linear guide ways and a rigid, servo-driven turret enable increased rapid travel speeds and smooth, heavy-duty cutting. A high-torque, high-power motor provides fast acceleration and deceleration movement while the absolute encoder technology eliminates the need for a limit switch. A high-performance V belt drive reduces maintenance and heat associated with gear-type drives.

Fig 4. LT-520 CNC LATHE.

The real power of the LT Series comes from the Mitsubishi M70V Series control and drive system. The control includes a state-of-the-art 64-bit RISC processing unit with ultra-high-speed fiber-optic backplane. This allows for extensive program look-ahead (337 blocks) and 33,700-BPM processing. The control software includes an easy-to-use interface with intuitive access to critical information such as editing, setup and monitoring functions. NAVI LATHE onboard programming includes a playback function for on the-fly program edits via teach mode. The navigation system allows for complete nano-processing—from the program values to the servo commands. The LT Series is available in three sizes and the two larger models are available with live tooling. All models feature a programmable tailstock and a top-of-the-line, front-conveyer chip-removal system.

CUTTING TOOL USED

Job Material : 25Cr-12 Ni TP309.

Tool material: S355J2G3 tungsten coated Carbide insert tool.

Table 1. Chemical Properties

Material	25Cr-12Ni TP309
C Max	0.22
Si Max	0.55
Mn Max	1.6
P Max	0.035
S Max	0.035
Cu Max	0.55

Table 2. Mechanical Properties

Material	25Cr-12Ni TP309
Yield Strength	0.22
Tensile Strength	0.55
Elongation (%)	1.6
Density	7.7
Hardness (BHN)	35

Fig.5. S355J2G3 tungsten coated Carbide insert tool

DESIGN OF EXPERIMENTS

Design of experiments (DOE) is a structured method that is used to identify relationships between several input variables and output responses. With the help of DOE, the resources needed to carry out the experiment can be optimized. Hence, it finds wide use in R & D studies. A few methods used as DOE are Taguchi Method, Response Surface Method and Factorial Designs. We will be focusing on the Response Surface Methodology during the ensuing study.

TAGUCHI METHOD

It is a statistical method used to improve the quality of manufactured product. According to Taguchi "Quality is the loss imparted to society from the time a product is shipped." Science experimental procedures are generally expensive and time consuming we need to satisfy the design objective with minimum number of tests. Taguchi method involves laying out the experimental condition using orthogonal array[9]. It is a specially constructed table which ensures that experiment design is both exploration needed to get the required design is significantly reduced. Hence testing time and experimental cost both are reduced. Orthogonal array provides much reduced variance for the experiment resulting optimum setting of process control parameter. It is carried in three step approach i.e. system design, parameter design, tolerance design. In system design, scientific and engineering principles are used to generate a prototype of the product that will encounter functional requirements. Parameter design is to optimize the settings of process parameter values for enlightening performance characteristics. And in tolerance design, tolerances are set around the target a value of the control parameter identified in the parameter design phase and is done only when the performance variation attained by the settings identified in the parameter design stage is unacceptable. Taguchi also defined a performance measure known as the signal to noise ratio (S/N) and aims to maximize it by properly selecting the parameter levels.

MATERIAL REMOVAL RATE MEASUREMENT

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

$$\text{Material removal rate (MRR)} = \frac{\text{Initial weight} - \text{final weight}}{\text{denisty} * \text{machining time}}$$

The weight of the work piece has been measured in a high precision digital balance meter (Model: DHD – 200 Macro single pan DIGITAL reading electrically operated analytical balance made by Dhona Instruments), which can measure up to the accuracy of 10g and thus eliminates the possibility of large error while calculating material removal rate (MRR) in straight turning operation.

EXPERIMENTAL OBSERVATION & ANALYSIS

Minitab statistical software has been used for the analysis of the experimental work. The Minitab software studies the experimental data and then provides the calculated results of signal-to-noise ratio. The objective of the present work is to minimize machining time and maximize the MRR in turning process optimization. The effect of different process parameters on material removal rate and machining time are calculated and plotted as the process parameters changes from one level to another. Taguchi Method is developed by Dr. Genichi Taguchi, a Japanese quality management consultant. The method explores the concept of quadratic quality loss function and uses a statistical measure of performance called Signal-to-Noise (S/N) ratio. The S/N ratio takes both the mean and the variability into account. The S/N ratio is the ratio of the mean (Signal) to the standard deviation (Noise). The ratio depends on the quality characteristics of the product/process to be optimized. The standard S/N ratios generally used are as follows: - Nominal is Best (NB), Lower the Better (LB) and Higher the Better. Its user-friendliness and appearance also add to its effectiveness. The average value of S/N ratios has been calculated to find out the effects of different parameters and as well as their levels. The use of both ANOVA technique and S/N ratio approach makes it easy to analyze the results and hence, make it fast to reach on the conclusion.

PROCESS PARAMETERS

The working ranges of the parameters for subsequent design of experiment, based on Taguchi's L9 Orthogonal Array (OA) design have been selected. In the present experimental study, spindle speed, feed rate and depth of cut have been considered as process variables. The process variables with their units (and notations) are listed in Table 3.

Factors	**Level 1**	**Level 2**	**Level 3**
Speed	80	90	100
Feed	0.05	0.1	0.15
Depth of cut	1	2	3

STEPS IN PERFORMING A TAGUCHI EXPERIMENT

Taguchi design of experiment is used to collect the data of cutting force and tool vibration. Minitab16 software is used to find the s/n ratio of grey relation grade and hence the optimal setting of input parameter. Minitab 16 software is used in this project work because it gives an easy technique to create, alter and review graphs. It also offers an active link between a graph and its worksheet hence helps in updating the graph automatically whenever the data is changed the process of performing a Taguchi experiment follows a number of distinct steps. They are

Step 1: formulation of the problem – the success of any experiment is dependent on a full understanding of the nature of the problem.

Step 2: identification of the output performance characteristics most relevant to the problem.
Step 3: identification of control factors, noise factors and signal factors (if any). Control factors are those which can be controlled under normal production conditions. Noise factors are those which are either too difficult or too expensive to control under normal production conditions. Signal factors are those which affect the mean performance of the process.
Step 4: selection of factor levels, possible interactions and the degrees of freedom associated with each factor and the interaction effects.
Step 5: design of a appropriate orthogonal array (OA).
Step 6: preparation of the experiment.
Step 7: running of the experiment with appropriate data collection.
Step 8: statistical analysis and interpretation of experimental results.
Step 9: undertaking a confirmatory run of the experiment.

RESULTS AND DISCUSSIONS

According to Taguchi's orthogonal array theory L9 orthogonal array is adopted for the whole experimentation for turning operation of 25Cr-12 Ni TP309 graded steel. In L9 orthogonal array, 9 experimental runs are conducted and the corresponding out puts is evaluated by Taguchi optimization technique. Table 3 shows the standard structure of L9 orthogonal array which levels of each parameters are taken as 1, 2 and 3 respectively.

Speed	Feed	Depth of Cut	SR	MRR	S/N ratio for SR	S/N rato for MRR
80	0.05	1	4.4	2598.00	-12.8691	-68.2952
80	0.1	2	1.8	2985.60	-5.10545	-69.5006
80	0.15	3	5.1	9566.88	-14.1514	-79.6154
90	0.05	2	3.99	3622.93	-12.0195	-71.1812
90	0.1	3	3.25	3125.60	-10.2377	-69.8987
90	0.15	1	3.65	7658.60	-11.2459	-77.683
100	0.05	3	4.25	5775.70	-12.5678	-75.2321
100	0.1	1	3.52	6894.50	-10.9309	-76.8827
100	0.15	2	2.99	9432.50	-9.51342	-79.4925

S.No	Speed	Feed	Depth of Cut
L1	80	0.05	1
L2	80	0.1	2
L3	80	0.15	3
L4	90	0.05	2
L5	90	0.1	3
L6	90	0.15	1
L7	100	0.05	3
L8	100	0.1	1
L9	100	0.15	2

Fig.6. Working piece after machining

TAGUCHI ANALYSIS

Table 4shows the experimental results for surface roughness and material removal rate corresponding S/N ratio.

Table 4 Response output for L9 orthogonal array using minitab

This graph indicates the influence of each process parameter on surface roughness, Response graph for Surface roughness is shown in Fig 16. A quality characteristic for surface roughness, can be considered as smaller is the better. Hence, it can be observed from Fig 7 that surface roughness is lower.

i. At first level of spindle speed i.e. 80 rpm.
ii. At second level of feed rate i.e. 0.1.mm/min
iii. At second level of depth of cut i.e. 2mm.

However, the significant and insignificant parameter will be discriminated based on percentage contribution of each factor toward surface roughness.

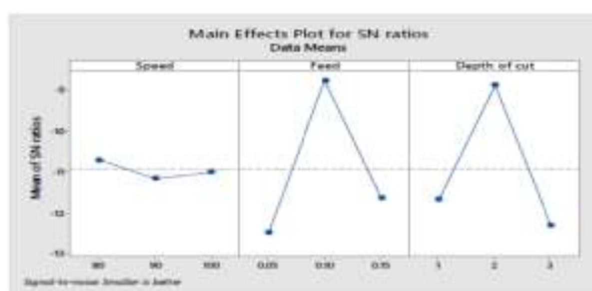

Fig.7. S/N Ratios for surface roughness (smaller is better).

From the graph it is concluded that the optimum combination of each process parameter for lower surface roughness is meeting at speed (A1), feed rate (B2) and depth of cut (C2). From the figure 17, it is evident that feed rate and depth of cut are more affecting parameters for surface roughness as compare to cutting speed. The optimal condition for the surface roughness is cutting speed = 80 rpm, feed rate = 0.10 mm/rev and depth of cut 2.0 mm. The response table is as shown below (Table5).

Level	Speed	Feed	Depth of Cut
1	-10.709	-12.485	-11.682
2	-11.168	-8.758	-8.879
3	-11.004	-11.637	-12.319
Delta	0.459	3.727	3.440
Rank	3	1	2

The influence of machining parameters on surface roughness can be obtained using response table 5. Response table shows the average response characteristics for each level of each factor in the design. The rank orders the factors based on the delta values in the response table from the highest effect to the least effect depending on the characteristics of the response. Table 4 shows the response table for S/N ratio in which it is clearly visible that feed is the most influencing factor since it is ranked first followed by Feed and Depth of cut in minimizing the surface roughness.

ANOVA

The analysis of variance (ANOVA) (shown in Table 6 was used to study the significance and effect of the cutting parameters on the response variables i.e. RA and MRR. Analysis of variance can be used to investigate and model the relationship between a response variable and independent variables. It was also carried out to verify the factors which are statistically significant at 95% confidence level with the help of the P-value. The P-value which is less than or equal to 0.05 indicates the higher level of significance. The last column of the ANOVA table shown in table 6 indicates the percentage of contribution (Pc) in which feed has the highest level of contribution (42.47%) followed by Depth of cut (36.3%) and The above table shows that, for surface roughness none of the parameters and no interactions have been found significant, since all the P Values are greater than 0.05 (Table 6).Anova analysis for surface roughness

Source	DF	Seq SS	Contribution %	Adj SS	Adj MS	F-Value	P-Value
Speed	2	0.05296	0.74	0.05296	0.02648	0.04	0.965
Feed	2	3.04709	42.47	3.04709	1.52354	2.07	0.325
Depth of Cut	2	2.60416	36.3	2.60416	1.30208	1.77	0.361
Error	2	1.47029	20.49	1.47029	0.73514	-	-
Total	8	7.17449	100	-	-	-	-

it was found that Feed and depth of cut are the two significant input parameters for MRR during machining with a P-Value of 0.000. No interactions between the input parameters have been found significant for the material removal rate values obtained at different experimental trial combinations are shown in Table 6. Instead of conducting '27' experimental trial combination by varying one factor at a time i.e. full factorial experiments, with the help of Taguchi's L9 Orthogonal array optimized condition can be obtained by analyzing the results of nine experimental trials. Interestingly the obtained optimum condition does not match with any of the experimental trial combination existing in L9 array. It can be observed that the material removal rate value obtained at optimum condition is less than any of the material removal rate values obtained experimentally as per L9Orthogonal array Followed by feed and depth of cut.

Table 7. Anova analysis for MRR

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Speed	2	12305713	19.76%	12305713	6152856	2.71	0.270
Feed	2	44452851	71.37%	44452851	22226426	9.79	0.093
Depth of cut	2	981879	1.58%	981879	490940	0.22	0.822
Error	2	4540673	7.29%	4540673	2270337		
Total	8	62281116	100.00%				

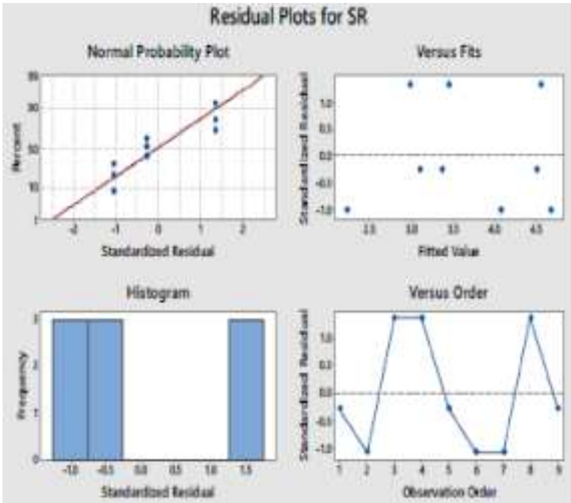

Fig 8. Interaction Plot for MRR

CONCLUSIONS

The following conclusions can be drawn after the experiment and study on turning of 25Cr-12 Ni TP309 with the carbide insert tool:

• Taguchi method can be efficiently used in off-line quality control in that the experimental design is combined with the quality loss
• From the study it is found that the main factors affecting more the feed rate and depth of cut. Cutting speed are less affecting as compared to the above two mentioned parameters.
• Speed at 80 m/min, Feed at 0.05 mm/rev & DOC at 2 mm showed optimum level condition.

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