Optimization Techniques in Turning Operation by using Taguchi Method

S. Mohan Kumar, K. Kiran Kumar

***Abstract:** Manufacturing of any product requires different machining processes to get desired finished component. This project refers to the optimization of process parameters in turning process using Taguchi method (L9) in order to obtain efficient Material Removal Rate (MRR). EN 24 is used as work-piece for carrying out experiment to optimize Material Removal Rate which is influenced by three machining parameters namely spindle speed, feed rate and depth of cut. Different experiments are done by varying one parameter and keeping other two fixed so that optimized value of each parameter can be obtained. In this project dry turning operation of EN 24 graded steel is performed using HSS tool. The range of cutting parameters at three levels are spindle speed (200, 350 and 500 rpm), feed rate (0.1, 0.15 and 0.2 mm/rev), depth of cut (1.0, 1.5 and 2.0 mm) respectively. Taguchi method is a good method for optimization of various machining parameters as it reduces number of experiments. Taguchi orthogonal array is designed with three levels of process parameters and ANOVA is applied to know the influence of each parameter on Material Removal Rate. For the given set of conditions, spindle speed influences more on Material Removal Rate followed by feed rate and depth of cut.*

***Keywords:** (L9), (MRR), (1.0, 1.5 and 2.0 mm), ANOVA, (200, 350 and 500 rpm), rate (0.1, 0.15 and 0.2 mm/rev),*

I. INTRODUCTION

Machining is any of various processes in which a piece of raw material is cut into a desired final shape and size by a controlled material-removal process. The many processes that have this common theme, controlled material removal, are today collectively known as subtractive manufacturing, in distinction from processes of controlled material addition, which are known as additive manufacturing.

Exactly what the "controlled" part of the definition implies can vary, but it almost always implies the use of machine tools (in addition to just power tools and hand tools).The precise meaning of the term machining has evolved over the past one and a half centuries as technology has advanced. In the 18th century, the word machinist simply meant a person who built or repaired machines.

This person's work was done mostly by hand, using processes such as the carving of wood and the hand-forging and hand-filing of metal. At the time, millwrights and builders of new kinds of engines (meaning, more or less, machines of any kind), such as James Watt or John Wilkinson, would fit the definition.

The noun machine tool and the verb to machine (machined, machining) did not yet exist. Around the middle of the 19th century, the latter words were coined as the concepts that they described evolved into widespread existence. Therefore, during the Machine Age, machining referred to (what we today might call) the "traditional" machining processes, such as turning, boring, drilling, milling, broaching, sawing, shaping, planing, reaming, and tapping.

In these "traditional" or "conventional" machining processes, machine tools, such as lathes, milling machines, drill presses, or others, are used with a sharp cutting tool to remove material to achieve a desired geometry. Since the advent of new technologies such as electrical discharge machining, electrochemical machining, electron beam machining, photochemical machining, and ultrasonic machining, the "conventional machining" can be used to differentiate those classic technologies from the newer ones. In current usage, the term "machining" without qualification usually implies the traditional machining processes.

Machining is a part of the manufacture of many metal products, but it can also be used on materials such as wood, plastic, ceramic, and composites. A person who specializes in machining is called a machinist. A room, building, or company where machining is done is called a machine shop. Machining can be a business, a hobby, or both Much of modern day machining is carried out by computer numerical control (CNC), in which computers are used to control the movement and operation of the mills, lathes, and other cutting machines.

The three principal machining processes are classified as turning, drilling and milling. Other operations falling into miscellaneous categories include shaping, planning, boring, broaching and sawing.

- Turning operations are operations that rotate the work piece as the primary method of moving metal against the cutting tool. Lathes are the principal machine tool used in turning.

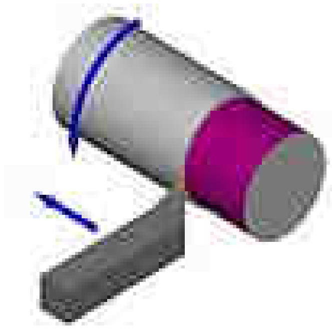

Fig.1.1 Turning Operation

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II. LITERATURE REVIEW:

2.1. Sing and Kumar (2006) [1] studied on optimization of feed force through setting of optimal value of process parameters namely speed, feed and depth of cut in turning of EN24 steel with TiC coated tungsten carbide inserts. The authors used Taguchi's parameter design approach and concluded that the effect of depth of cut and feed in variation of feed force were affected more as compare to speed.

2.2. Ahmed (2006) [2] developed the methodology required for obtaining optimal process parameters for prediction of surface roughness in Al turning. For development of empirical model nonlinear regression analysis with logarithmic data transformation was applied. The developed model showed small errors and satisfactory results. The study concluded that low feed rate was good to produce reduced surface roughness and also the high speed could produce high surface quality within the experimental domain.

2.3. Mahmoud and Abdelkarim (2006) [3] studied on turning operation using High-Speed Steel (HSS) cutting tool with 45^0 approach angle. This tool showed that it could perform cutting operation at higher speed and longer tool life than traditional tool with 90 degree approach angle. The study finally determined optimal cutting speed for high production rate and minimum cost, tool like, production time and operation costs.

2.4. Bala Murugan Gopalsamy, Biswanath Mondal and Sukamal Ghosh (2009) [4] studied the performance characteristics of machining parameters (cutting speed, feed, depth of cut and width of cut) with consideration of surface finish and tool life. Chipping and adhesion are observed to be main causes of wear. Results obtained by Taguchi method match closely with ANOVA and cutting speed is most influencing parameter.

2.5. Rama Rao S, Padmanabhan. G, (2012) [5] considered LM6 Al/5%SiC composites, which are fabricated by stir casting route, were machined by ECM process and investigated the influence of the various process parameters, i.e. voltage, feed rate and electrolyte concentration on the the metal removal rate (MRR).

2.6. Ashish Yadav, Ajay Bangar, Rajan Sharma, Deepak Pal (2012) [6] investigated the relation between change in hardness caused on the material surface due the turning operation with respect to different machining parameters like spindle speed, feed and depth of cut have been investigated. Taguchi method has been used to plan the experiments and EN 8 metal selected as a work piece and coated carbide tool as a tool material in this work and hardness after turning has been measured on Rockwell scale.

2.7. M. Kaladhar, K. Venkata Subbaiah, Ch. Srinivasa Rao ,(2012) [7] conducted experiment on AISI 304 austenitic stainless steel work pieces which are turned on computer numerical controlled (CNC) lathe by using Physical Vapour Deposition (PVD) coated cermet insert (TiCN TiN) of 0.4 and 0.8 mm nose radii. The results revealed that the feed and nose radius is the most significant process parameters on work piece surface roughness. However, the depth of cut and feed are the significant factors on MRR.

2.8. Ranganath M S, Vipin (2013) [8] investigated the parameters affecting the roughness of surfaces produced in the turning process for the various materials studied by researchers. Design of experiments were conducted for the analysis of the influence of the turning parameters such as cutting speed, feed rate and depth of cut on the surface roughness. The results of the machining experiments were used to characterize the main factors affecting surface roughness by the Analysis of Variance (ANOVA) method Taguchi's parametric design is the effective tool for robust design it offers a simple and systematic qualitative optimal design to a relatively low cost.

2.9. T. Sreenivasa Murthy, R.K.Suresh, G. Krishnaiah, V. Diwakar Reddy, (2013) [9] determined the influence of process parameters on the surface roughness during the machining operation of En 41B alloy steel with cermet tool. Experiments have been carried out by using Taguchi design. The feed and speed are identified as the most influential process parameters on work piece surface roughness

2.10. Vikas B. Magdum, Vinayak R. Naik, (2013) [10] investigated the use of tool materials and process parameters for machining forces for selected parameter range and estimation of optimum performance characteristics. Develop a methodology for optimization of cutting forces and machining parameters.

2.11.Taquiuddin Quazi, Pratik gajanan more, (2014) [11] studied Taguchi methods to optimize surface roughness in turning mild steel, EN-8 and EN-31. The turning parameters evaluated are cutting speed of 200, 250, and 300 m/min, feed rate of 0.08, 0.12 and 0.15 mm/rev, depth of cut of 0.5 mm and tool grades of TN60, TP0500 and TT8020, each at three levels. The experiment was designed and carried out on the basis of standard L9 Taguchi orthogonal array.

2.12.Anand S.Shivade, Shivraj Bhagat, Suraj Jagdale, Amit Nikam, Pramod londhe, (2014) [12] designed and conducted experiments based on Taguchi's L9 Orthogonal array design. The parameters like surface roughness and tool tip temperature were optimized using single point carbide Cutting Tool. The Analysis of Variance (ANOVA) is employed to analyze the influence of Process Parameters during Turning.

III. OBJECTIVE OF WORK:

The objective of work is to observe the cutting parameters in turning and to calculate the optimum value of the parameters in order to optimize the surface roughness and tool wear using Taguchi method. The statistical analysis is to be performed for better machining operation which can be used for quality control of machining parts. This will help to concerned R&D researchers or industrial experts.

Taguchi methods provide a cost effective, efficient and systematic way to optimize designs for performance, quality, and cost. This method has been used successfully in designing reliable, high-quality products at low cost in such areas as automotive, aerospace, and consumer. Cutting forces, surface roughness and tool wear are among the most important technical parameters in machining process.

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Cutting forces are necessary for evaluation of machine tool components and the tool body. Cutting forces influences the deformation of the work piece machined, its dimensional accuracy, machine stability and chip formation.

IV. EXPERIMENTAL WORK

4.1. Cutting Tool Specification

The specification of cutting tool used is single point cutting tool and the dimensions are as follows.

Table 4.1: Specification of cutting tool

Specification of cutting tool (mm) Cutting Edge Length	Inscribed Circle or Height	Thickness	Hole Diameter	Corner Radius	Side Clearance
12.7	12.7	4.76	5.16	0.8	0°

Table 4.2: chemical composition for single point cutting tool

Grade	C	Cr	Mo	W	V	Co	Mn	Si
T1	0.65–0.80	4.00	-	18	1	-	0.1–0.4	0.2–0.4
M2	0.95	4	5	6.0	2.0	-	-	-
M7	1.00	4	8.75	1.75	2.0	-	-	-
M36	0.94	4	5	6.0	2.0	8.0	-	-
M42	1.10	3.75	9.5	1.5	1.15	8.0	-	-

4.2. Composition and Application of Work Piece

EN24 is a high tensile alloy steel renowned for its wear resistance properties and also where high strength properties are required. EN24 is a most widely used austenitic steel popularly known as 18/8 stainless steel. The Figure 4.1 shows the experimental set up of turning operation with work piece of EN24 graded steel.

Fig 4.1 Experimental Setup

4.3. Physical data

Table 4.3: EN24 steel physical data

Density (lb/cu.inch)	0.285
Specific Gravity	7.9
Specific Heat (Btu/lb/Deg F)	0.12
Electrical Resistivity (micro.ohm-cm)	432
Melting Point (Deg F)	2650
Modulus of Elasticity Tension	28

4.4. Composition

EN24 is a (1.5% Ni,Cr,Mo) steel in US equivalent to SAE 4340,Chemical Composition % - Carbon 0.35-0.45/ Silicon 0.10-0.35/ Manganese 0.45-0.70/ Nickel 1.30-1.80 / Chromium 0.90-1.40/ Moly 0.20-0.35/ Sulphur 0.050 (max)/ Phosphorous 0.050(max).Mechanical Properties -Limiting Ruling Section (in) - 6Tensile Strength (tons/sq.in.) - 55 (min) Proof Stress (tons/sq.in.) - 41 (min) Elongation % - 18 (min) Izod Impact Value (Ft.Lb.) 40(min) Weldability – POOR Application - High tensile steel suitable for pump shafts and turbine rotors in general and for similar uses. Non-preferred but sometime used in place of EN 27 steel when the later not available

Typical chemical composition of En24

Table 4.4: Chemical composition of EN24 Steel

C	Mn	Mo	Cr	Ni	P	S	Si
0.36/0.44	0.45/0.70	0.20/0.35	1.00/1.4	1.3/1.7	0.035max.	0.04max.	0.10/0.35

Table 4.5: Mechanical Properties of EN24 Steel

Size (mm)	Tensile Strength N/mm²	Yield Stress N/mm²	Elongation	Impact Izod J	Impact KCV J	Hardness HB
63-150	850-1000	680min	13%	54	50	248/302
150-250	850-1000	654min	13%	40	35	248/302

4.5. Material Notes

Essentially non-magnetic, becomes slightly magnetic when cold worked, it has excellent corrosion and forming characteristics and highly ductile. This has corrosion resistance mostly with oxidizing acids and salt spray.

- EN24 is usually supplied in the T condition with a tensile strength of 850/1000 N/mm
- EN24 is a popular grade of through hardening alloy steel due to its excellent machinability in the "T" condition.

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EN24T is used in components such as gears, shafts, studs and bolts.

- EN24T can be further surface hardened to create components with enhanced wear resistance by induction or nitriding processing.

4.6. Applications

This steel is widely used in petrochemical industries, diary, household and pharmaceutical purposes and cryogenic vessels, and as heat exchanger in air conditioning refrigeration factories.

4.7. Procedure followed for experimentation

First of all, the work-piece (EN 24) is mounted on the head stock of lathe. The other end of material is center-bored using center drill and then fixed with the tail stock respectively. Then, according to the design of experiment (Table 5.1), different levels of parameters are set to get 9 numbers of run.

The work piece was given initial roughness pass. Statistical analysis of obtained data carried out using Taguchi optimization technique

V. METHODOLOGY:

5.1. Introduction to Taguchi Method

Taguchi method is a powerful tool for the design of high quality systems. It provides simple, efficient and systematic approach to optimize designs for performance, quality and cost. Taguchi method is efficient method for designing process that operates consistently and optimally over a variety of conditions. To determine the best design it requires the use of a strategically designed experiment.

Taguchi approach to design of experiments in easy to adopt and apply for users with limited knowledge of statistics, hence gained wide popularity in the engineering and scientific community. The desired cutting parameters are determined based on experience or by hand book. Cutting parameters are reflected steps of Taguchi method are as follows:

5.2. Design of experiments

Experiments were designed using Taguchi method which uses an OA to study the entire parametric space with a limited number of experiments. In present research two parameter (factors) chosen such as speed and depth of cut. All of them were set at three different levels.

Table 5.1: Level Values of Input parameters

S. No.	Feed (mm/min)	Depth of Cut (mm)	Speed (RPM)
1	0.1	1.0	200
2	0.15	1.5	350
3	0.2	2.0	500

Selection of a particular OA is based on the number of levels of various factors. Here, 3 parameters each at 3 levels, therefore Degree of Freedom (DOF) can be calculated as, Eq.1

(DOF) = P (L – 1) ………… (1)

P = number of factors, L = number of levels

(DOF) = 3 (3 – 1) = 6

Total DOF of Orthogonal Array (OA) should be greater than or equal to the total DOF required for the experiment, here 9 > 6 hence L9 OA is selected. Each machining parameter is assigned to a column of OA and 9 machining parameter combinations are designed. Material removal rate is the response variable is chosen for the present investigation.

ADVANTAGES:

- An advantage of the Taguchi method is that it emphasizes a mean performance characteristic value close to the target value rather than a value within certain specification limits, thus improving the product quality.
- Additionally, Taguchi's method for experimental design is straightforward and easy to apply to many engineering situations, making it a powerful yet simple tool. It can be used to quickly narrow down the scope of a research project or to identify problems in a manufacturing process from data already in existence.
- The Taguchi method allows for the analysis of many different parameters without a prohibitively high amount of experimentation. For example, a process with 8 variables, each with 3 states, would require 6561 (3^8) experiments to test all variables.
- However using Taguchi's orthogonal arrays, only 18 experiments are necessary, or less than 0.3% of the original number of experiments. In this way, it allows for the identification of key parameters that have the most effect on the performance characteristic value so that further experimentation on these parameters can be performed and the parameters that have little effect can be ignored.

5.3. ANOVA (Analysis Of Variance)

The main aim of ANOVA is to investigate the design parameters and to indicate which parameters are significantly affecting the output parameters. In the analysis, the sum of squares and variance are calculated. F-test value, at 95 % confidence level is used to decide the significant factors affecting the process and percentage contribution is calculated.

The ANOVA analysis for percentage calibration is shown in Table 6.7. ANOVA can be useful for determining influence of any given input parameter from a series of experimental results by design of experiments for machining process and it can be used to interpret experimental data. Analysis of variance (ANOVA) is a collection of statistical models, and their associated procedures, in which the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides statistical information to select the optimum values for Material Removal Rate (MRR).

ANOVA is a particular form of statistical hypothesis testing heavily used in the analysis of experimental data. A statistical hypothesis test is a method of making decisions using data.

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A test result (calculated from the null hypothesis and the sample) is called statistically significant if it is deemed unlikely to have occurred by chance, assuming the truth of the null hypothesis. A statistically significant result, when a probability (p-value) is less than a threshold (significance level), justifies the rejection of the null hypothesis, but only if the a priori probability of the null hypothesis is not high.

In the typical application of ANOVA, the null hypothesis is that all groups are simply random samples of the same population. For example, when studying the effect of different treatments on similar samples of patients, the null hypothesis would be that all treatments have the same effect (perhaps none). Rejecting the null hypothesis would imply that different treatments result in altered effects.

By construction, hypothesis testing limits the rate of Type I errors (false positives leading to false scientific claims) to a significance level. Experimenters also wish to limit Type II errors (false negatives resulting in missed scientific discoveries). The Type II error rate is a function of several things including sample size (positively correlated with experiment cost), significance level (when the standard of proof is high, the chances of overlooking a discovery are also high) and effect size (when the effect is obvious to the casual observer, Type II error rates are low).

The terminology of ANOVA is largely from the statistical design of experiments. The experimenter adjusts factors and measures responses in an attempt to determine an effect. Factors are assigned to experimental units by a combination of randomization and blocking to ensure the validity of the results. Blinding keeps the weighing impartial. Responses show a variability that is partially the result of the effect and is partially random error.

VI. RESULTS & DISCUSSIONS

6.1. Introduction

According to Taguchi's orthogonal array theory L9 orthogonal array is adopted for the whole experimentation for turning operation of EN 24 graded steel. In L9 orthogonal array, 9 experimental runs are conducted and the corresponding out puts is evaluated by Taguchi optimization technique. Table 6.1 shows the standard structure of L9 orthogonal array which levels of each parameters are taken as 1, 2 and 3 respectively.

Table 6.1: Taguchi orthogonal array

S. No.	Cutting speed (RPM)	Feed (m/min)	Depth of cut (mm)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	3
5	2	2	1
6	2	3	2
7	3	1	2
8	3	2	3
9	3	3	1

Here, the process variables are cutting speed, feed rate and depth of cut. These are the input parameters for the Taguchi optimization. So, nine experiments are carried out as per this orthogonal array and corresponding output data are recorded serially. The full structure of experimentation is tabulated in Table 6.4 as per L9 orthogonal array.

6.2. Process Parameters:

There are three process parameters are considered for optimizing the material removal rate for a set of conditions on Lathe machine. They are feed, spindle speed and depth of cut and their values are tabulated as follows.

Table 6.2: Input parameters with various levels

S. No.	Feed (mm/min)	Depth of Cut (mm)	Speed (RPM)
1	0.1	1.0	200
2	0.15	1.5	350
3	0.2	2.0	500

6.3. Material Removal Rate Calculations:

1. **Cutting Speed**, Vc = π .D.N

Where, Vc = cutting speed in mm/min

D = diameter of work piece in mm

N = spindle speed in Revolutions per Minute (RPM)

2. **Material Removal Rate:**

Material Removal Rate (MRR) =adc. f. Vc

Where, adc = depth of cut in mm

f = feed in mm/min

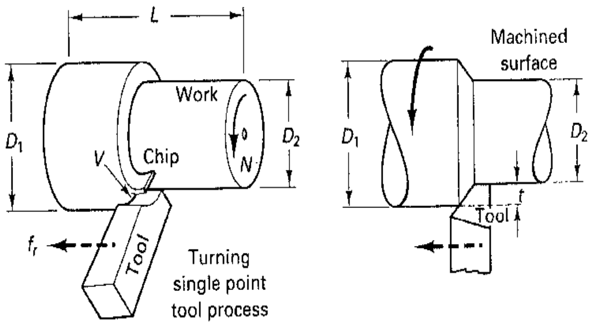

Fig. No.6.1: Turning Operation Using Single Point Cutting Tool

A. Machine Speed: To achieve a specific cutting speed:

$$N = \frac{k * V}{\pi * D_1}$$

N = machine speed in revolutions/minute (RPM)

K is a constant to "correct" speed (V) and part diameter (D_i) units

V is desired cutting speed, a Handbook Value

D_1 is largest part diameter (initial size)

V given in surface feet per minute (SFPM), D_1 in inches: k = 12

V given in meters per second (MPS), D_1 in mm: k = 60000

V given in meters per minute (MPM), D_1 in mm: k = 1000

If Cutting Speed for a given RPM rate is desired, solve above equation for V =πND/k

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B. Cutting Time: minutes per operation
CT is cutting time per "pass"
L is length cut
A is "allowance" or starting offset
f_r is machine feed rate units/revolution, a Handbook Value

$$CT = \frac{(L + A)}{f_r * N}$$

As taking 'D' as Diameter of the work piece in mm and 'N' as machine speed in revolutions/minute and 'k' as constant. Hence we calculate the cutting time (CT) and Material Removal Rate. As we know that adc = depth of cut in mm and f = feed in mm/min and't' is Depth of cut (inch or mm)

B. Material Removal Rate (MRR or Q)

$$= \frac{\text{Volume Removed}}{\text{Cutting time}}$$

$$MRR = \frac{\pi * L\,(D_1^2 - D_2^2)}{\frac{4L}{f_r N}}$$

D_2 is Finished Diameter

$$MRR = k\, f_r\, V \left[\frac{D_1 - D_2}{2}\right] * \left[\frac{D_1 + D_2}{2D_1}\right]$$

$$\left[\frac{D_1 - D_2}{2}\right] \approx t$$

$$\left[\frac{D_1 + D_2}{2D_1}\right] \approx 1$$

Substituting for N from above considered formula, Material Removal Rate (MRR) can be obtained.
Therefore:

$$MRR \approx k\, V\, f_r\, t$$

6.4. Taguchi Method Applications:

Taguchi method is applied for optimizing the values of Material Removal Rate for EN 24 steel at a given set of conditions on Lathe machine. For this L9 orthogonal array is used as shown in below table

S.No.	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	3
5	2	2	1
6	2	3	2
7	3	1	2
8	3	2	3
9	3	3	1

Table 6.3: L9 Orthogonal Array

S. No.	Feed (mm/min)	Speed (RPM)	Depth of Cut (mm)
1	0.1	200	1.0
2	0.1	350	1.5
3	0.1	500	2.0
4	0.15	200	2.0
5	0.15	350	1.0
6	0.15	500	1.5
7	0.2	200	1.5
8	0.2	350	2.0
9	0.2	500	1.0

Table 6.4: Experiments Conducted

S. No.	Speed (RPM)	Feed (mm/min)	Depth of Cut (mm)	Material Removal Rate –MRR (mm^3/min)
1	200	0.1	1.0	1570.796
2	350	0.1	1.5	4123.341
3	500	0.1	2.0	7853.98
4	200	0.15	2.0	1570.796
5	350	0.15	1.0	4712.388
6	500	0.15	1.5	8835.727
7	200	0.2	1.5	4712.388
8	350	0.2	2.0	10995.576
9	500	0.2	1.0	7853.98

Table 6.5: Material Removal Rate for different Input parameter combinations

Parameters	L_1	L_2	L_3
Spindle Speed	2418	4515	8181
Feed Rate	4516	5040	7854
Depth Of Cut	4712	5890	6807

Table 6.6: Influence of each Process Parameter on Material Removal Rate

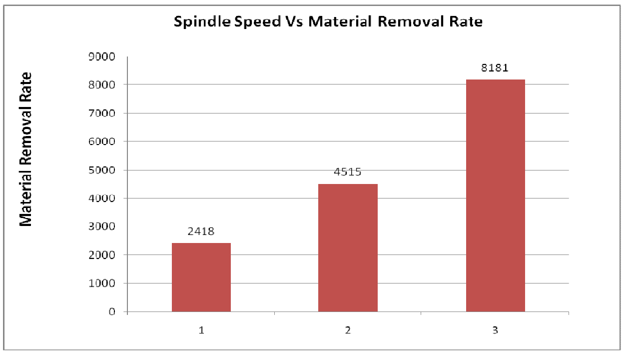

Fig 6.1a Influence of Spindle speed on Material Removal Rate

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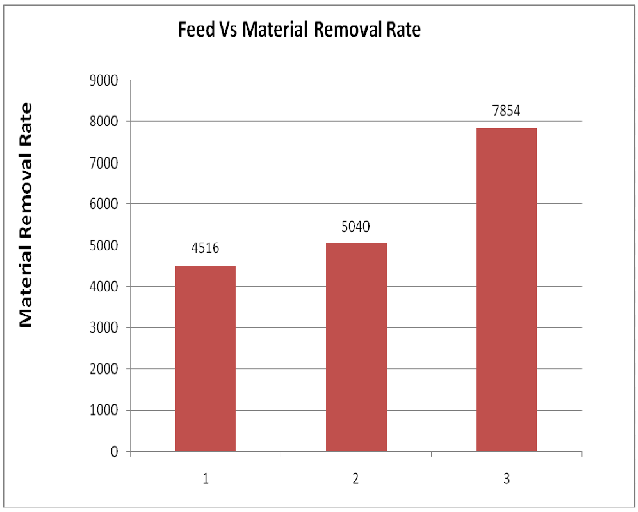

Fig 6.1b Influence of Feed on Material Removal Rate

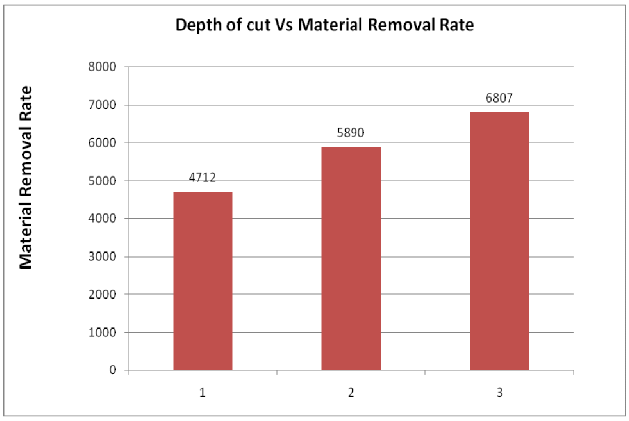

Fig 6.1c Influence of Depth of Cut on Material Removal Rate

6.5. Response Graph

This graph indicates the influence of each process parameter on material removal rate. Response graph for material removal rate is shown in Fig 6.1. A quality characteristic for material removal rate can be considered as higher is the better. Hence, it can be observed from Fig 6.1 that material removal rate is higher

i. At second level of spindle speed i.e. 350 rpm
ii. At third level of feed rate i.e. 0.2.mm/min
iii. At third 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 Material Removal Rate.

6.5.1. ANOVA

The material removal rate values obtained at different experimental trial combinations are shown in Table 6.5, Analysis of variance (ANOVA) is performed and results are given in Table 6.7. Percentage contribution of each factor is depicted in the form of bar graph in Fig 6.2. It can be observed from Fig 6.2 that spindle speed has got major contribution towards variation in material removal rate followed by feed and depth of cut.

Hence, speed and feed are significant parameters which are higher percentage of contribution must be maintained at the levels specified i.e., feed rate at level-3, Depth of cut at level-3 and Spindle speed at level-2.

Table 6.7: Analysis of Variance (ANOVA) for Material Removal Rate

Source	DOF	Seq. Sum of Squares	Adjacent Mean Squares	% Contribution
Feed	2	1.92E+07	9.60E+06	13.00431219
Speed	2	6.95E+07	3.48E+07	47.07290091
Depth of cut	2	6.61E+06	3.31E+06	4.477005396
Error	8	52333333	26166667	35.4457815
Total		1.48E+08		100

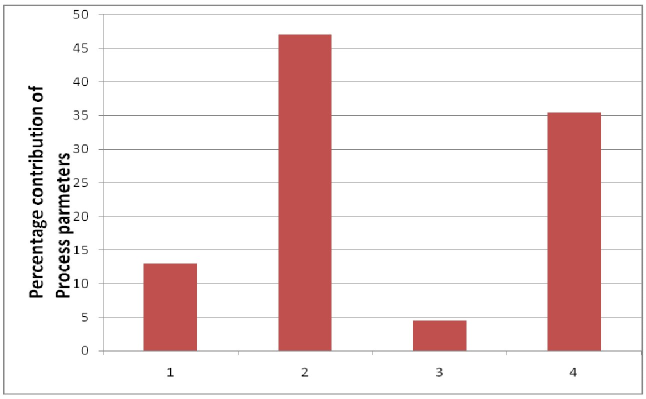

Figure 6.2: % Contribution on Material Removal Rate

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 L_9 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 L_9 Orthogonal array.

6.5.2. S/N Ratio for Material Removal Rate:

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".

After finding all the observation as given in Table 6.5 and 6.6, S/N ratio is calculated and various graph for analysis is drawn by using Minitab 15 software. The S/N ratio for MRR is calculated on Minitab 15 Software using Taguchi Method.

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The S/N ratio for the larger-the-better is:

$$\frac{S}{N} = -10\log_{10}\left\{\frac{1}{n}\sum\frac{1}{y^2}\right\} \text{........ (1)}$$

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 Eqn. 1 with the help of software Minitab 15. The MRR values measured from the experiments and their corresponding S/N ratio values are listed.

Feed (mm/min)	Depth of Cut (mm)	Speed (RPM)	MRR	S/N Ratio
0.1	200	1.0	1570.796	71.38
0.1	350	1.5	4123.341	67.10
0.1	500	2.0	7853.98	74.56
0.15	200	2.0	1570.796	72.10
0.15	350	1.0	4712.388	75.53
0.15	500	1.5	8835.727	71.38
0.2	200	1.5	4712.388	77.40
0.2	350	2.0	10995.576	78.24
0.2	500	1.0	7853.98	74.94

Table6.8: Response for Signal to Noise Ratios

S. No.	Feed (mm/min)	Depth of Cut (mm)	Speed (RPM)
1	0.1	1.0	200
2	0.15	1.5	350
3	0.2	2.0	500
Delta	6.02	11.14	3.57
Rank	2	1	3

Table 6.9: Ranking for the input parameters

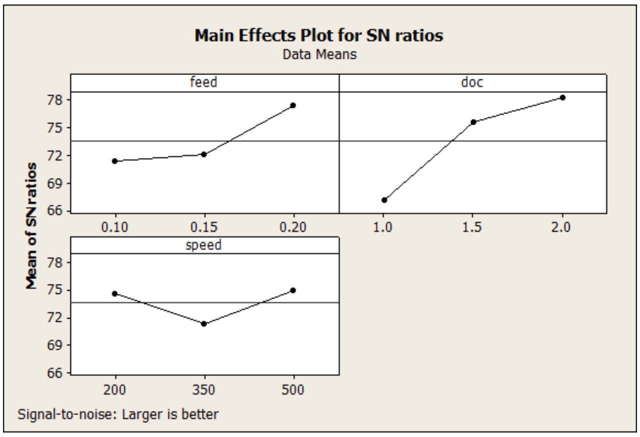

Figure: 6.3 The S/N ratios for Material Removal Rate

VII. CONCLUSIONS

• Conclusion can be derived from the experimentation done using EN 24 graded steel and High Speed Steel cutting tool.

• A set of levels of parameter is obtained in order to maximize the material removal rate.

•Regardless of the category of the performance characteristics, a greater S/N value corresponds to a better performance. Therefore, the optimal level of the machining parameters is the level with the greatest value.

Spindle Speed:-The effect of parameters spindle speed on the metal removal rate values is shown figure 6.3 for S/N ratio. Its effect decreases up to 350 RPM and increases with increase in spindle speed up to 500 RPM. So the optimum spindle speed is level 2 i.e. 350 RPM

Feed Rate:-The effect of parameter feed rate on the metal removal rate values is shown figure in 6.3 for S/N ratio. Its effect is increasing with increase in feed rate. So the optimum feed rate is level 3 i.e. 0.2 mm/min.

Depth of Cut:-The effect of parameters depth of cut on the metal removal rate values is shown in figure 6.3 for S/N ratio. Its effect is increasing with increase in depth of cut. So the optimum depth of cut is level 3 i.e. 2 mm.

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