"Optimization of Turning Process parameters in machining Heat Treated Steel using Taguchi Technique"

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In

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by

MOHAMMAD SHAHID

Enrollment No: - 1300100263

Under the Supervision of

Mr. Yaqoob Ali Ansari

DEPARTMENT OF MECHANICAL ENGINEERING,

INTEGRAL UNIVERSITY, LUCKNOW

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Lucknow

CERTIFICATE

This is to certify that the thesis work entitled "**Optimization of turning process parameters in machining Heat Treated Steel using Taguchi Technique**" submitted by MOHAMMAD SHAHID, **Enrollment No.** 1300100263 in partial fulfillment for the award of **Master of Technology** degree in **Mechanical Engineering Department** with specialization in Production and Industrial Engineering, to Integral University, Lucknow (U.P.). He has carried out his thesis work under my supervision and guidance and to the best of my knowledge; the matter embodied in this thesis has not been submitted to any other University/Institute for award of any degree to the candidate or to anybody else.

Date:

Mr.Yaqoob Ali Ansari
(Assistant Professor)
Department of Mechanical Engineering
Integral University, Lucknow

ABSTRACT

Today competitive market demands efficient manufacturing with high quality, optimum manufacturing cost and environmental sustainability consideration. This is achieved by advanced engineering materials and automated machining.

Automation has helped in achieving an economical implementation of resources in the machining process without compromising the high levels of quality produced and productivity. The change in the market demands and product specification requires higher production rates and consistency and uniformity of the manufactured parts.

The present experimental research on turning studies the process parameters that are affecting the machining performance and productivity of Plain Turning. A combined approach is used for the optimization of parameters and performance characteristics based on Taguchi method. The design of experiments is based on Taguchi's L_9 orthogonal array. The response table and response graph for each level of machining parameters are obtained from Taguchi method to select the optimal levels of machining parameters. In the present work, the machining parameters are Speed, Feed Rate and Depth of Cut, which are optimized for maximum material removal rate (MRR) and minimum Surface Roughness during turning of Heat Treated Steel (EN-9). Analysis of Variance is also used to find out variable affecting the various responses mentioned above.

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Md. Shahid

Place: Lucknow

Mohammad Shahid

Date:

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INTRODUCTION

1.1 Introduction

Today competitive market demands efficient manufacturing with high quality, optimum manufacturing cost and environmental sustainability consideration. This is achieved by advanced engineering materials and automated machining.

Automation has helped in achieving an economical implementation of resources in the machining process without compromising the high levels of quality produced and productivity. The change in the market demands and product specification requires higher production rates and consistency and uniformity of the manufactured parts.

New industrial applications require materials with advanced properties for products particular requirements with reliable and economical manufacturing processes and higher productivity. These advanced engineering materials are used in automotive, aerospace, electronics, medical applications and others industries. The advanced and modified properties will improve the quality of these materials and help meet certain mechanical, electrical, or chemical requirements. Typical properties that are needed are tensile strength, hardness, thermal conductivity, and corrosion and wear resistance.

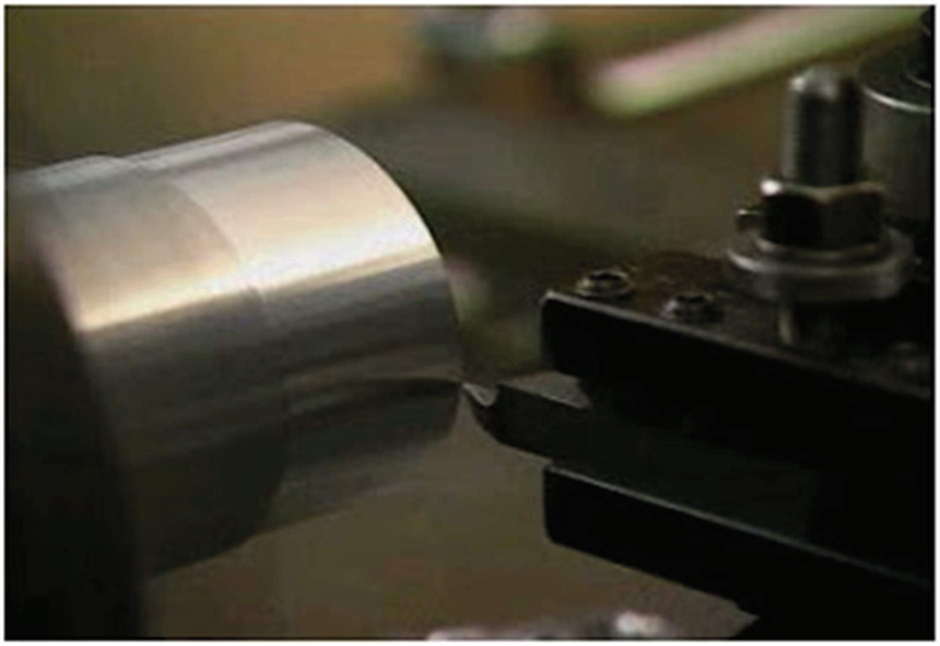

Figure 1.1 Turning operation

The turning operation is a basic metal machining operation that is used widely in all industries that deals with metal cutting. Machining parameters selection for a turning operation is a very important task in order to accomplish high performance and productivity. Higher performance mean better machinability, better surface finish, lesser rate of tool wear, better material removal rate, higher rate of production, etc.

In turning, the material is removed from the work piece in form of chips. The work piece in turning process is rotated while the tool is moved towards the work piece with a certain velocity. It is done usually to produce conical, curved and grooved shapes on the work piece. Metal cutting processes are industrial processes in which metal parts are shaped or removal of unwanted material. It is one of the most important and widely used manufacturing processes in engineering industries. A significant improvement in output quality may be obtained by optimizing the cutting parameters. Optimization of parameters not only improves output quality, but also ensures low cost manufacturing. The important cutting parameters include feed rate, cutting speed, depth of cut, cutting fluids and so on. In turning process, cutting parameters plays a vital role in the efficient use of machine tool.

Lathe machine is the oldest machine tool that is still the most common used machine in the manufacturing industry to produce cylindrical parts. It is widely used in variety of manufacturing industries including aerospace and automotive sectors, where quality of surface plays a very important role in the performance of turning as good-quality turned surface is significant in improving fatigue strength, corrosion resistance, and creep life.

On surfaces produced by machining and abrasive operations, the irregularities produced by the cutting action of tool edges and abrasive grains and by the feed of the machine tools are called surface roughness. It is the irregularity of primary texture. Roughness may be considered as being superposed on a wavy surface.

The maximum height or the roughness form produced by a single point cutting tool is given by

$$\mathbf{H_{max} = \frac{f^2}{8R}}$$

Where f is feed rate and R is nose radius.

The CLA or centre line average value of surface roughness (Ra) (as per the BS-1134) is the arithmetical average of the departure of the whole of the profile both above and below its centerline throughout the prescribed meter cut-off in a plane substantially normal to the surface.

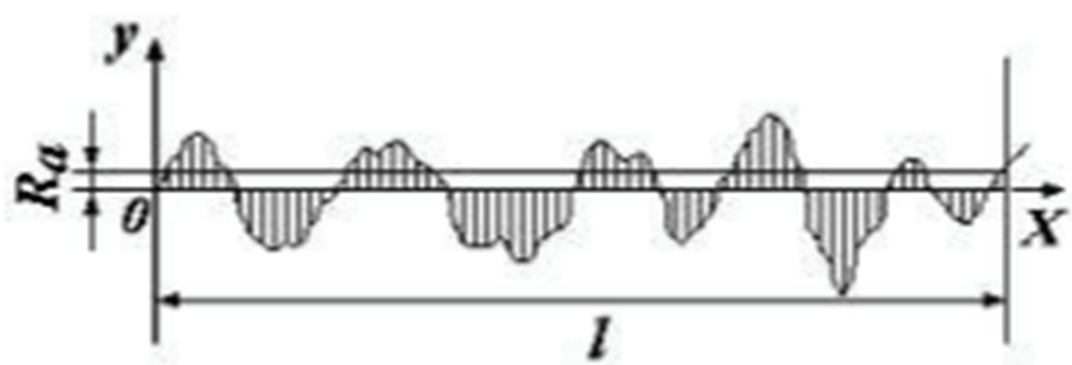

Fig. 1.2 Average surface roughness (Ra)

During the past few years, unprecedented progress has been made in the hard turning. The greatest advantage of using hard turning is the reduced machining time and complexity required to manufacture metal parts. Before few years problem associated with the hard turning was the generation of high temperature in cutting zone. This adversely affects the quality of the products produced. Cutting fluids have been the conventional choice to deal with this problem. But, the application of conventional cutting fluids creates some techno-environmental problems like environmental pollution, biological problems to operators, water pollution, Further; the cutting fluids also incur a major portion of the total manufacturing cost.

1.2 Turning Operation

Turning is the removal of metal from the outer diameter of a rotating cylindrical work piece. Turning is used to reduce the diameter of the work piece, usually to a specified dimension, and to produce a smooth finish on the metal. Often the work piece will be turned so that adjacent sections have different diameters. Turning is the machining operation that produces cylindrical parts. In its basic form, it can be defined as the machining of an external surface:

- With the work piece rotating.
- With a single-point cutting tool, and
- With the cutting tool feeding parallel to the axis of the work piece and at a distance that will remove the outer surface of the work.

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. 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.

Application of solid lubricant in dry machining has proved to be a feasible alternative to cutting fluid, if it can be applied properly. Advancement in modern tribology has identified many solid lubricants like graphite, boric acid, hexagonal boron nitride (White graphite), molybdenum disulfide and tungsten disulfide, which can sustain and provide lubricity over a wide range of temperatures. If suitable solid lubricant can be applied in a more refined and defined way.

Machining operations have been the core of the manufacturing industry since the industrial revolution. The existing optimization researches for computer numerical controlled (CNC) turning were either simulated within particular manufacturing circumstances or achieved through numerous frequent equipment operations. Nevertheless, these are regarded as computing simulations, and the applicability to real-world industry is still uncertain. Therefore, a general deduction optimization scheme without equipment operations is deemed to be necessarily developed.

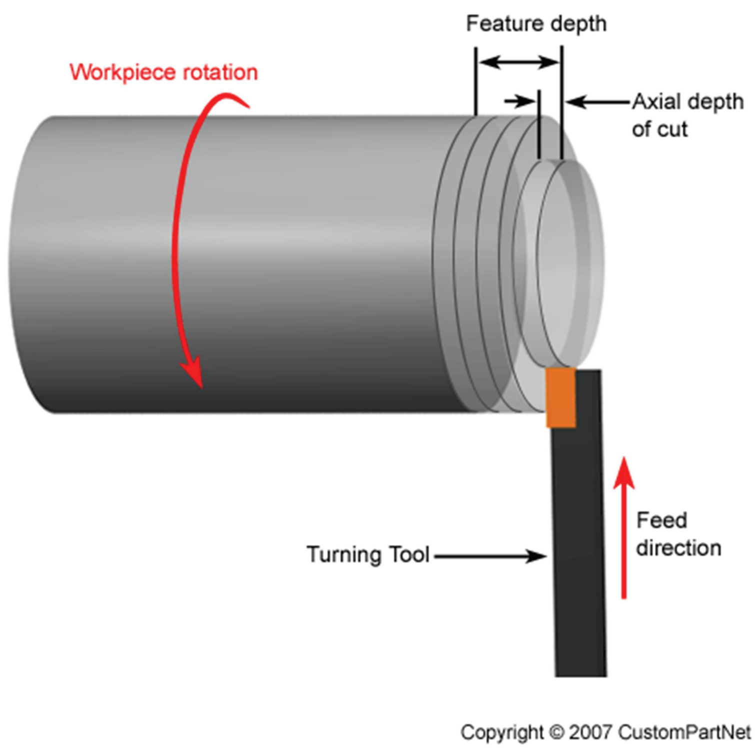

Figure 1.3 Basic mechanism of Turning

The machining process on a CNC lathe is programmed by speed, feed rate, and cutting depth, which are frequently determined based on the job shop experiences. However, the machine performance and the product characteristics are not guaranteed to be acceptable. Therefore, the optimum turning conditions have to be accomplished. It is mentioned that the tool nose runoff will affect the performance of the machining process. Therefore, the tool nose runoff is also selected as one of the control factors in this study.

Manufacturing enterprises presently have to deal with growing demands for improved product quality, greater product unpredictability, shorter product life-cycles, cheap cost, and global struggle. In the field of machining, manufacturers are turning increasingly more often to automation as an effective way to meet these demands. A solution issue for an unattended and automated machining system is the development of reliable and robust monitoring systems. Turning is the removal of metal from the outer diameter of a rotating cylindrical work piece.

1.3 Factors affecting the Surface Finish

Whenever two machined surfaces come in contact with one another the quality of the mating parts plays an important role in the performance and wear of the mating parts. The height, shape, arrangement and direction of these surface irregularities on the work piece depend upon a number of factors such as:

A) The machining variables which include

a) Cutting speed

b) Feed, and

c) Depth of cut.

B) The tool geometry

Some geometric factors which affect achieved surface finish include:

a) Nose radius

b) Rake angle

c) Side cutting edge angle, and

d) Cutting edge.

C) Work piece and tool material combination and their mechanical properties

D) Quality and type of the machine tool used,

E) Auxiliary tooling, and lubricant used, and

F) Vibrations between the work piece, machine tool and cutting tool.

1.4 Factors influencing Surface Roughness in Turning

Generally, it is found that the factors influencing surface roughness in turning are:

(i) Depth of cut:

Increasing the depth of cut increases the cutting resistance and the amplitude of vibrations. As a result, cutting temperature also rises. Therefore, it is expected that surface quality will deteriorate.

(ii) Feed:

Experiments show that as feed rate increases surface roughness also increases due to the increase in cutting force and vibration.

(iii) Cutting speed:

It is found that an increase of cutting speed generally improves surface quality.

(iv)Engagement of the cutting tool:

This factor acts in the same way as the depth of cut.

(v) Cutting tool wears:

The irregularities of the cutting edge due to wear are reproduced on the machined surface. Apart from that, as tool wear increases, other dynamic phenomena such as excessive vibrations will occur, thus further deteriorating surface quality.

(vi) Use of cutting fluid:

The cutting fluid is generally advantageous in regard to surface roughness because it affects the cutting process in three different ways. Firstly, it absorbs the heat that is generated during cutting by cooling mainly the tool point and the work surface. In addition to this, the cutting fluid is able to reduce the friction between the rake face and the chip as well as between the flank and the machined surface. Lastly, the washing action of the cutting fluid is considerable, as it consists in removing chip fragments and wear particles. Therefore, the quality of a surface machined with the presence of cutting fluid is expected to be better than that obtained from dry cutting.

(vii) Three components of the cutting force:

It should be noted that force values cannot be set a priori, but are related to other factors of the experiment as well as to factors possibly not included in the experiment, i.e. force is not an input factor and is used as an indicator of the dynamic characteristics of the work piece—cutting tool—machine system.

Finally, the set of parameters including the above mentioned parameters that are thought to influence surface roughness, have been investigated from the various researchers.

1.5 Advantages of Turning Process

- All materials are compatible.
- Very good tolerances.
- Short lead times.
- High machining rate.

1.6 Disadvantages of Turning Process

- Limited to rotational parts.
- Part may require several operations and machining.
- High equipment cost.
- Significant tool wear
- Large amount of scrap produced.

1.7 Applications of Turning Process

In turning, the raw form of the material is a piece of stock from which the work pieces are cut. This stock is available in a variety of shapes such as solid cylindrical bars and hollow tubes. Custom extrusions or existing parts such as castings or forgings are also sometimes used.

Turning can be performed on a variety of materials, including most metals and plastics. Common materials that are used in turning include Aluminum, Brass, Magnesium, Nickel, Steel, Thermoset plastics, Titanium and Zinc.

Basically turning operation is used in manufacturing of machine components, engine cylindrical components, shafts and other rotational components.

When selecting a material, several factors must be considered, including the cost, strength, resistance to wear, and machinability. The machinability of a material is difficult to quantify, but can be said to posses the following characteristics:

- Results in a good surface finish
- Promotes long tool life
- Requires low force and power to turn
- Provides easy collection of chips

2

LITERATURE REVIEW

2.1 Literature Review

S.R. Das et al [1] conducted experiments on Tungsten AISI 4340 steel with Coated Graphite tool inserts. Feed was found to be most significant parameter for the workpiece surface roughness (Ra) with a percent contribution of 52.55%. Cutting speed was found to be the next significant parameter for Ra with contribution of 25.85%. Depth of cut was found a negligible influence in case of Ra.

Jitendra. M. Varma et al [2] conducted experiments on AISI 4340 using solid lubricant with coated carbon tool inserts. It is concluded that the application of solid lubricant in dry machining has proved to be a feasible alternative to cutting fluid, if it can be applied properly. There is a considerable improvement in surface roughness and quality of product produced.

Karanam Krishna et al [3] carried an investigation using ANN for material removal rate on Aluminum in turning. This work investigated the influence of the operating parameters like feed rate, depth of cut, clamping length and spindle speed. It was evident that each of these parameters studied contributed to the error in the dimensions of the machined component. Depth of cut and the feed rate had more effect on the accuracy than the other parameters. Based on this ANN prediction, the NC program could be corrected before commencing the actual machining operation, thus improving the accuracy of the component at less cost and time.

A.Sathyavathi et al [4] carried a study on different researches conducted. The most of researchers are interested in optimization of machining condition with corresponding surface roughness. In past reviewed found, none of researcher involved for TiBN coated cemented carbide tool. In this paper uncoated carbide tool and PVD (TiBN) coated carbide tool involved for performance of quality of surface and optimization of cutting parameter with aid of DOE and GA.

M.M.A. Khan et al [5] carried an investigation to analyze the effects of minimum quantity lubrication on turning AISI 9310 alloy steel using vegetable oil-based cutting fluid. They concluded that the chips produced under both dry and wet condition are of ribbon type continuous chips at lower feed rates and more or less tubular type continuous chips at higher feed rates. The significant contribution of MQL jet in machining the low alloy steel by the carbide insert undertaken has been the reduction in flank wear, which would enable either remarkable improvement in tool life or enhancement of productivity (MRR) allowing higher cutting velocity and feed. The Surface finishes also improved mainly due to reduction of wear and damage at the tool-tip by the application of MQL.

M. Venkata Ramana et al [6] carried experiments to study the effect of process parameters on tool wear in Turning of Titanium Alloy under different machining conditions It was concluded that the MQL machining shows advantage mostly by reducing tool wear as well as environmental problems, which reduces the friction between the chip - tool interaction. Using ANOVA, the effect each individual factors on tool wear found to be significance and the contribution of cutting speed is more followed by tool material, depth of cut, feed rate and coolant condition in order to minimizing tool wear.

Vikas B. Magdum et al [7] carried investigation to evaluate and optimize the machining parameters for turning of EN 8 steel using HSS M2, Carbide and Cermet tools.

N.Zeelan Basha et al [8] optimized turning process parameters on Aluminium 6061 using Genetic Algorithm. Optimum surface finish was obtained at maximum cutting speed, minimum feed and minimum depth of cut.

Y.B. Kumbhar et al [9] investigated tool life and surface finish optimization of PVD TiAlN/TiN multilayer coated Carbide tool inserts in semi hard turning of hardened EN-31 alloy steel under dry cutting conditions. Maximum tool life is obtained at low cutting speed, moderate feed and depth of cut. Feed rate was found to be the most significant factor for tool life. Feed rate was also the most significant factor for surface roughness.

Gopal Krishna, P. V et al [10] studied the effect of cryogenic processing and carried out experiments on cryogenic treated tools in turning. Significant influence is seen on tool life which gets improved up to 90%. They concluded that the life of the tools has increased due to cryogenic treatment while machining both soft and hard materials. The cryogenic treated tools are found to be most productive at high speeds and feeds.

Hemant B. Patil et al [11] reviewed the effects of cryogenic on tool steels. It was concluded that cryogenic induces wear resistance as the soft austenite is converted into hard martensite. The dimensional accuracy and surface finish also get improved. They also concluded that the use of cryogenic increases the cutting force which can be reduced by the use of secondary liquid nitrogen.

Lakhwinder Pal Singh et al [13] compared cryogenic treated and un-treated high speed steel tool in turning. It was concluded that after cryogenic treatment of high speed steel the performance of the tool was enhanced. Less power consumption was observed.

M.Dhananchezian et al [14] investigated the effects of cryogenic cooling by liquid nitrogen in orthogonal turning of Ti-6Al-4V. The cryogenic reduces the cutting temperature. The cutting force was found to be increased. The chip thickness was reduced by 25% as compared to dry turning.

S. Thamizhmanii et al [15] in their study of lowest surface roughness in turning SCM 440 alloy steel found that depth of cut was the most significant factor for surface roughness. Feed rate was the second most influencing factor for surface roughness.

C R Barik et al [16] studied roughness characteristics of surface roughness generated in CNC turning of EN 31 alloy steel and optimization of machining parameters based on Genetic Algorithm. The investigation concluded that the surface roughness get decrease on decreasing feed rate but it is constant with range of cutting speed. The surface roughness also decreases with decrease in depth of cut.

Ajeet Kumar Rai et al [17] investigated the effect of cutting parameters (cutting speed, feed rate, and depth of cut) on surface roughness in a turning operation of cast iron. The results shows that cutting speed, feed rate and depth of cut affects the surface roughness. The cutting speed was the most significant factor for the surface roughness while there was no significant effect of depth of cut on surface roughness.

Feng and Wang [18] investigated for the prediction of surface roughness in finish turning operation by developing an empirical model through considering working parameters: work piece hardness (material), feed, cutting tool point angle, depth of cut, spindle speed, and cutting time. Data mining techniques, nonlinear regression analysis with logarithmic data transformation were employed for developing the empirical model to predict the surface roughness.

Suresh et al. [19] focused on machining mild steel by TiN-coated tungsten carbide (CNMG) cutting tools for developing a surface roughness prediction model by using Response Surface Methodology (RSM). Genetic Algorithms (GA) used to optimize the objective function and compared with RSM results. It was observed that GA program provided minimum and maximum values of surface roughness and their respective optimal machining conditions.

Lee and Chen [20] highlighted on artificial neural networks (OSRR-ANN) using a sensing technique to monitor the effect of vibration produced by the motions of the cutting tool and work piece during the cutting process developed an on-line surface recognition system. The authors employed tri-axial accelerometer for determining the direction of vibration that significantly affected surface roughness then analyzed by using a statistical method and compared prediction accuracy of both the ANN and SMR.

2.2 Objective of present work

Above study shows that the major factors for plain turning are cutting speed, feed rate and depth of cut for the performance measures i.e., material removal rate and surface roughness. Thus on the basis of above study parameters cutting speed (V_c), feed (f) and depth of cut (d) are selected for this work to analyze the material removal rate and surface roughness by using machining parameters selected as V_c, f and d using Taguchi design approach

1. To find influence on MRR with V_c, f and d.

2. To find influence on Surface Roughness with V_c, f and d.

2.3 Different Phases of Experimentation

To accomplish the objectives, present work has been done in two phases

Phase -I

- Development of experimental set up providing varying range of input parameters in turning and measuring the various responses on-line and off-line.
- Investigation of the working ranges and the levels of the turning process parameters (pilot experiments) affecting the selected quality characteristics, by using one factor at a time approach.

Phase –II

- Investigation of the effects of turning process parameters on quality characteristics viz. material removal rate and surface roughness while machining EN-9.
- Optimization of quality characteristics of machined parts:
- Prediction of optimal sets of turning process parameters
- Prediction of optimal values of quality characteristics
- Prediction of confidence interval (95%CI)
- Experimental verification of optimized individual quality characteristics

The Taguchi's parameter design approach has been used to obtain the above objectives.

3

TAGUCHI APRROACH

3.1 Taguchi Method

Taguchi has developed a methodology for the application of designed experiments, including a practitioner's handbook. This methodology has taken the design of experiments from the exclusive world of statistician and brought it more fully into the world of manufacturing [21]. His contributions have also made the practitioner work simpler by advocating the use of fewer experimental designs, and providing a clear understanding of the variation nature and the economic consequences of quality engineering in the world of manufacturing. Taguchi introduces his approach, using experimental design for:

- Designing products/processes so as to be robust to environmental conditions;
- Designing and developing products/processes so as to be robust to component variation;
- Minimizing variation around a target value. This philosophy of Taguchi is broadly applicable. He proposed that engineering optimization of a process or product should be carried out in a three step approach i.e. system design, parameter design and tolerance design. In system design the engineer applies scientific engineering knowledge to produce a basic functional prototype design. In the product design stage the selection of the materials, components, tentative product parameter values etc. are involved. Since system design is an initial step, functional design may be far from optimum in terms of quality and cost.

The objective of parameter design is to optimize the setting of process parameter value for improving performance characteristics and to identify the product parameter values under the optimal process parameter values. In addition, it is expected that the optimal process parameter values obtained from the parameter design are insensitive to the variation of environmental conditions and other noise factors. Therefore, the parameter design is the key step in Taguchi method of achieving high quality without increasing cost. Basically, classical parameter design developed by Fisher is complex and not easy to use especially, a large number of experiments have to be carried out when the number of process parameters increases. To solve this task, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. A loss function is then defined to calculate the deviation between the experimental values and desired values. Taguchi recommends the use of the loss function to measure the performance characteristic deviating from the desired value. The value of the loss function is further transformed into a signal-to-noise (S/N) ratio. Usually there are three categorize of performance characteristic in the analysis of the S/N ratio that is the lower-the-better, the higher-the-better, and the nominal-the –better. The S/N ratio for each level of process parameter is computer based on the S/N analysis. Regardless of the category of the performance characteristic, the larger S/N ratio corresponds to the better performance characteristic. Therefore, the optimal level of the process parameter is the level with the highest S/N and ANOVA analysis, the optimal combination of the process parameters can be predicted. Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the parameter design. The Taguchi method is adopted to obtain optimal machining performance in the die sinking.

1. **Larger is better (maximum) : $S/N_{LB} = -10 \log ((1/n) \Sigma (1/y_i^2))$**

2. **Smaller is better (minimum) : $S/N_{SB} = -10 \log ((1/n) \Sigma y_i^2)$**

Where, n is the number of observations or repetitions of a trial and y is the observed data. Notice that these S/N ratios are expressed on a decibel scale. We would use S/NT if the objective is to reduce variability around a specific target, S/NL if the system is optimized when the response is as large as possible, and S/N'S if the system is optimized when the response is as small as possible. Factor level that optimizes the appropriate S/N ratio is optimal.

The use of parameter design of the Taguchi method to optimize a process with multiple performance characteristics includes the following steps:

- Identify the performance characteristics and select process parameters to be evaluated.
- Determine the number of levels for the process parameters and possible interactions between the process parameters.
- Select the appropriate orthogonal array and assignment of process parameters to the orthogonal array.
- Conduct the experiments based on the arrangement of the orthogonal array.
- Analyze the experimental results using S/N ratio and ANOVA.
- Select the optimal level of process parameters.
- Verify the optimal process parameters through the confirmation experiment.

3.2 APPLICATION OF S/N RATIO

The change in the quality characteristics of a product under investigation, in response to a factor introduced in the experiment design is the signal of desired effect. However, when an experiment is conducted, there are numerous external factors not designed into the experiment which influence the outcome. These external factors are called the noise factors and their effect on the outcome of the quality characteristic under test is termed as noise. The signal to noise ratio measures the sensitivity of the quality characteristic being investigated in a controlled manner, to those external influencing factors (noise factors) not under control. The concept of S/N ratio originated in the electrical engineering field. Taguchi effectively applied this concept to establish the optimum condition from the experiments.

The aim of any experiment is always to determine the highest possible S/N ratio for the result. A high value of S/N ratio implies that the signal is much higher than the random effect of the noise factors. Product design or process operation consistent with highest S/N ratio, always yields the optimum quality with minimum variance.

From the quality point of view, there are three possible categories of quality characteristics. They are:

1. Smaller is better;
2. Nominal I better;
3. Larger is better.

The S/N ratio is designed to measure the quality characteristics.
The Signal to Noise ratio (S/N ratio) expresses the scatter around a target value. The larger the ratio, the smaller is the scatter. Knowing the S/N ratio of the samples before and after the experiment, Taguchi's loss function may be used to estimate the potential cost saving from the improved product.

3.3 Advantage Of S/N Ratio Over Average

To analyze the results of experiments involving multiple runs, use of the S/N ratio over standard analysis is preferred. Analysis using the S/N ratio will offer the following main advantages:

1. It provides guidance to a selection of optimum level based on least variation around the target and also on the average value closest to the target.
2. It offers objective comparison of two sets of experimental data with respect to variation around target and the deviation of the average from the target value.

3.4 Role of ANOVA

Taguchi replaces the full factorial experiment with a lean, less expensive, faster, partial factorial experiment. Taguchi's design for the partial factorial is based on specially developed OA's. Since the partial experiment is only a sample of the full experiment, the analysis of the partial experiment must include an analysis of the confidence that can be placed in the results. Fortunately, there is a standard statistical technique called Analysis of Variance (ANOVA) which is routinely used to provide a measure of confidence. The technique does not directly analyze the data, but rather determine the variability (variance) of the data. Confidence is measured from the variance.
Analysis provides the variance of controllable and noise factors. By understanding the source and magnitude of variance, robust operating conditions can be predicted. This is second benefit of the methodology.

3.5 Analysis of Variance (ANOVA):

This method was developed by Sir Ronald Fisher in the 1930's as a way to interpret the results from agricultural experiments. ANOVA is not a complicated method and has a lot of mathematical beauty associated with it. ANOVA is a statistically based, objective decision-making tool for detecting and differences in average performance of groups of items tested. The decision rather than using pure judgment, takes variation into account.

3.6 Tables for Taguchi Design of Experiment

Tables for Taguchi design of experiment are shown below:

Table 3.1: Process Parameters and their levels

S.No.	**Parameters**	**Units**	**Level 1**	**Level 2**	**Level 3**
1	Speed	RPM	300	450	600
2	Feed	mm/rev	0.1	0.2	0.3
3	Depth of Cut	mm	0.2	0.4	0.6

Table 3.2: L9 Orthogonal Array

Exp. No	**Speed (RPM)**	**Feed (mm/rev)**	**Depth of Cut (mm)**
1	300	0.1	0.2
2	300	0.2	0.4
3	300	0.3	0.6
4	450	0.1	0.4
5	450	0.2	0.6
6	450	0.3	0.2
7	600	0.1	0.6
8	600	0.2	0.2
9	600	0.3	0.4

4

EXPERIMENTATION

4.1 Experimental Setup

Experiments are conducted on ACE CNC Turning Machine. The machine is as shown in the figure below. The material is removed from the work-piece by the linear motion of tool towards work-piece in form of chips.

Table 4.1 Specifications of ACE CNC Turning Machine

Model	JOBBER LM
Type of Guideways	Linear motion Guideways
X axis stroke	114 mm
Z axis stroke	200 mm
X and Z axis motor torque	2.6 Nm
Number of tools Maximum	8
Control System	Ace
Coolant Tank Capacity	60 litre
Overall Machine Dimensions (LBH)	1650*1350*1720 in mm
Overall Machine Weight	1850 kg
Maximum Spindle Speed	4000
Spindle Motor Power	5.5 kw
Standard Chuck Size	135 mm

The machine for experiments was available at RR Institute of Modern Technology, Lucknow.

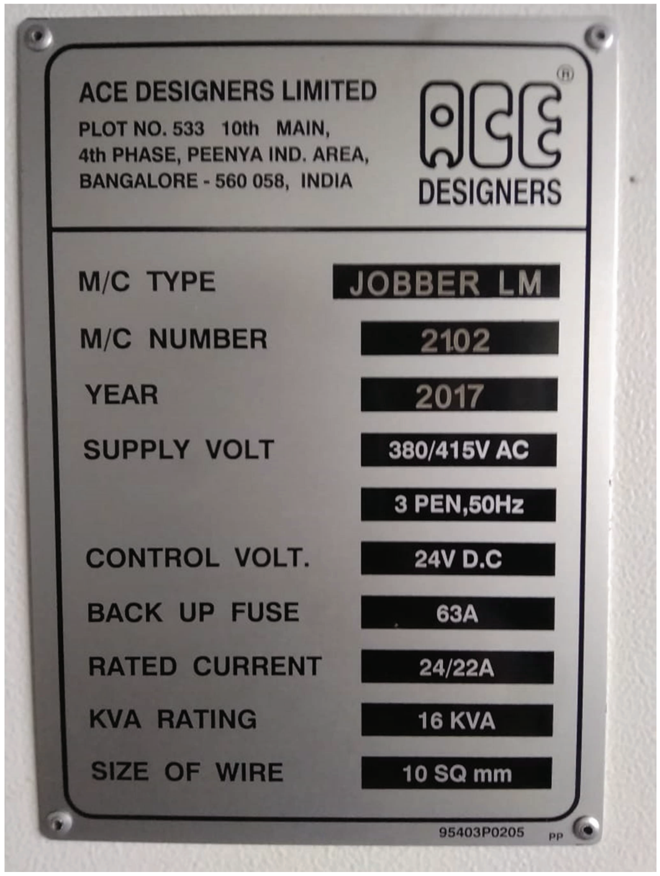

Figure 4.1 Specifications of CNC Turning Machine at RRIMT, Lucknow

Figure 4.2 CNC Turning Machine at RRIMT, Lucknow

Figure 4.3 ACE CNC Turning Machine with Heat Treated Steel (EN-9) Specimen

Figure 4.4 Turning of Heat Treated Steel Specimen

4.2 Work Piece Material

The material used for the present work is EN-9 (heat teated) with specification of 20 mm diameter. EN-9 Carbon steel is a medium carbon steel. It can be flame or induction hardened to produce a high surface hardness with excellent wear resistance .When hardened and tempered, it develops a tensile strength in the range 700-1000 N/mm depending on ruling section.

Table 4.2 Properties of EN-9

Density g/cm³	Melting point ºC	Yeild strength MPa	Elastic modulus Gpa	Possion's Ratio	Brinell Hardness
7.85	1427	417	196	0.3	217

Table 4.3 Chemical composition of the workpiece material (EN-9) by weight

Material	Fe	S	Mn	P	C	Si
% Composition	97.7	0.05	0.87	0.05	0.5	0.28

Figure 4.5: Workpiece Bars of EN-9 (heat treated)

Figure 4.6: EN-9 (heat treated) specimens after machining on CNC turning machine

EN-9 steel (heat treated) is suitable for engineering applications which require higher strength and wear resistance. Typical applications includes shafts, axes, knives, bushes, crankshafts, screws, sprockets ,springs, cylinders, cams, sickles, wood working drills, small gears, machine tools, keys and hammers.

4.3 Tool Material

HSS tool is used as tool for the present work.

4.4 Measurements

The objective of this thesis work is to calculate the material removal rate and surface roughness by the influence of cutting speed, feed and depth of cut.

4.4.1 Material Removal Rate

The rate of material removal from the work piece is known as material removal rate. Material is removed from the bar in form of chips. The material removal rate is calculated by multiplying the speed in mm/min with feed in mm/rev and depth of cut in mm. Higher the material removal rate higher is the productivity. Hence it is most desirable to increase the material removal rate. Firstly the speed is converted from RPM into m/min from the formula given below.

$$\mathbf{Speed\ in}\,\frac{\mathbf{m}}{\mathbf{min}} = \mathbf{Shaft\ Diameter\ (mm) x\ Speedin\ RPM\ x\ 0.001\ x\ \pi}$$

The formula for material removal rate is as shown under.

$$\boldsymbol{MRR = 1000\ \times Speed\ in\frac{m}{min} \times feed\ in\frac{mm}{rev} \times depth\ of\ cut\ in\ mm}$$

4.4.2 Surface Roughness

Surface roughness shows the quality of the machining or a job. It is desirable to decrease the surface roughness of the work-piece, as much as we lower the surface roughness the surface finish of the work piece will increase and the quality of the machining will improve. Surface roughness measurements are made using Stylus type profilometer TALYSURF surface roughness tester. Figure shows the TALYSURF surface roughness tester.

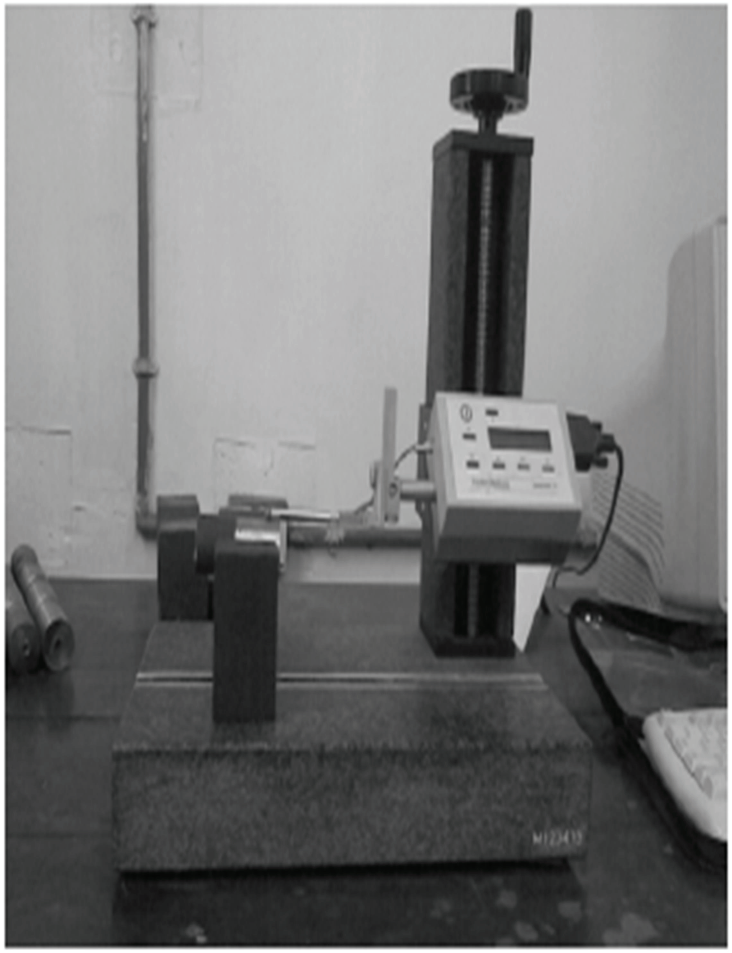

Figure 4.7 Stylus Type Profilometer

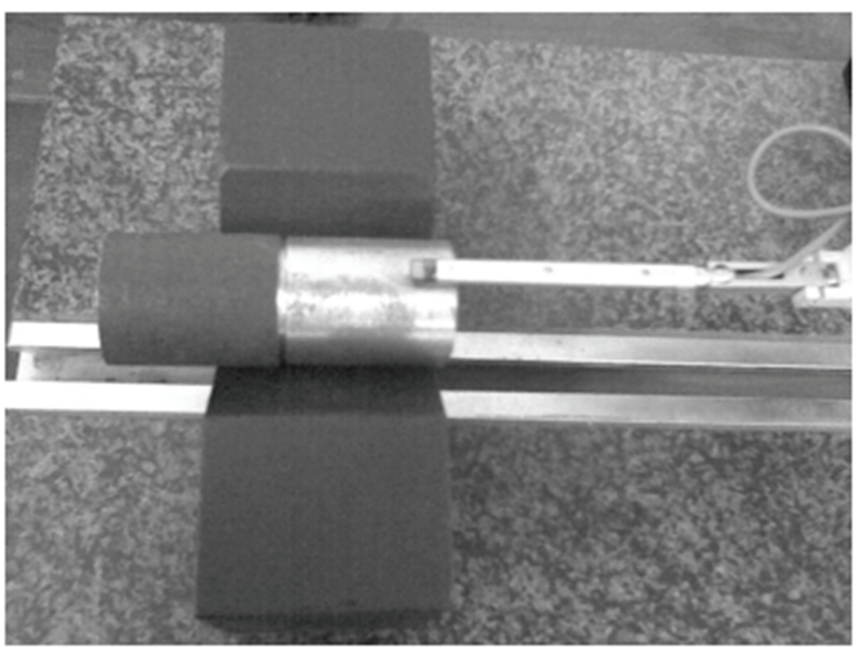

Figure 4.8 : Stylus during surface roughness measurement

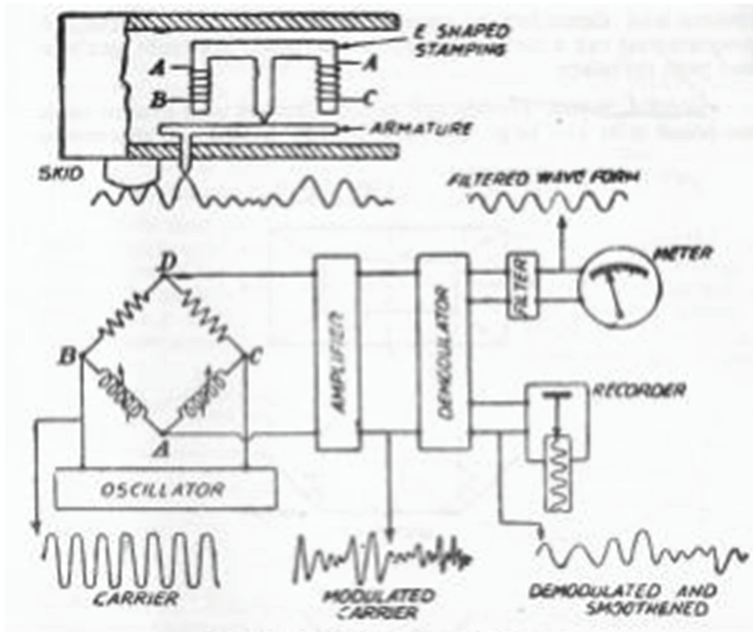

Figure 4.9 : Schematic Layout of Talysurf

4.5 Machining Parameters

The turning operation is governed by geometry factors and machining factors. This study consists of the three primary adjustable machining parameters in a basic turning operation viz. speed, feed and depth of cut. The figure shows these three parameters. Material removal is obtained by the combination of these three parameters. Other input factors influencing the output parameters such as surface roughness exist.

Cutting Speed

Cutting speed may be defined as the rate at which the uncut surface of the work piece passes the cutting tool. It is also defined as the relative surface speed between the tool and the work piece. It is expressed in meters per minute (m/min). It is often referred to as surface speed and is ordinarily expressed in m/min, though ft./min is also used as an acceptable unit. Cutting speed can be obtained from the spindle speed. The spindle speed is the speed at which the spindle, and hence, the work piece, rotates. It is given in terms of number of revolutions of the work piece per minute i.e. rpm. If the spindle speed is N rpm, the cutting speed V_c (in m/min) is given as

$$Vc = \frac{\pi DN}{1000}$$

Where D = diameter of the work piece in mm.

The cutting speed to be used depends on the following factors:

1. Work material.
2. Cutting tool material.
3. The depth of cut and feed.
4. Desired cutting tool life.
5. Rigidity and conditions of the machine and tool and the rigidity of the work.

In our study the cutting speed is varied as 50, 100 and 150 RPM.

Feed

It may be defined as the relatively small movement per cycle of the cutting tool, relative to the work piece in a direction which is usually perpendicular to the cutting speed direction. Feed is the distance moved by the tool tip along its path of travel for every revolution of the work piece. It is denoted as f and is expressed in mm/rev. Sometimes, it is also expressed in terms of the spindle speed in mm/min as

$$F_m = f\,N$$

where, f = Feed in mm/rev

N = Spindle speed in rpm.

Feed to be used depends on the following factors:

1. Smoothness of finish required
2. Power available, condition of machine and its drive
3. Type of cut
4. Tool life.

In our study the feed is varied as 0.06, 0.10 and 0.14 mm/rev.

Depth of cut

Depth of cut (d) is defined as the distance from the newly machined surface to the uncut surface. It is also defined as the thickness of the layer of metal removed in one cut, or pass, measured in a direction perpendicular to the machined surface. In other words, it is the thickness of material being removed from the work piece. It can also be defined as the depth of penetration of the tool into the work piece measured from the work piece surface before rotation of the work piece. The diameter after machining is reduced by twice of the depth of cut as this thickness is removed from both sides owing to the rotation of the work.

$$d = \frac{D_1 - D_2}{2}$$

where, D_1 = Initial diameter of job

D_2 = Final diameter of job

Depth of cut to be used depends on the following factors:

1. Type of cut
2. Tool life
3. Power required.

In our study depth of cut is varied as 0.2, 0.4 and 0.6 mm.

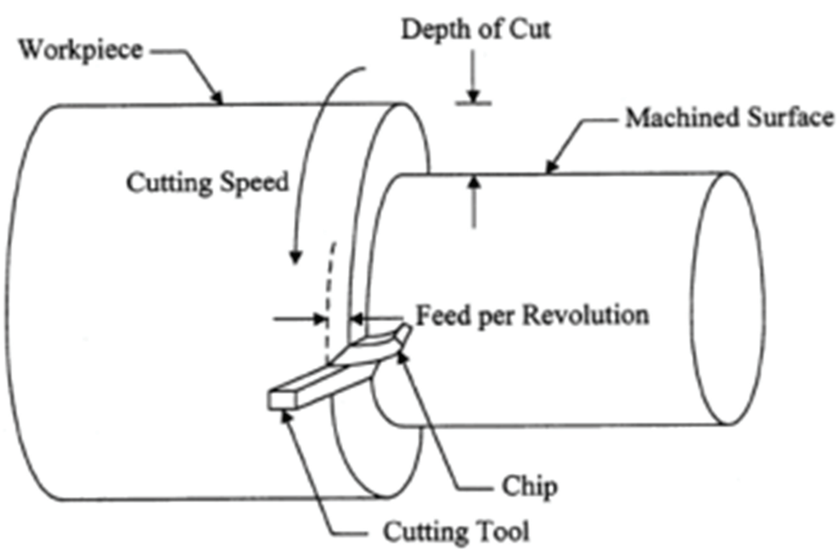

Figure 4.10 : The Adjustable Machining Parameters

5

Results and Discussion

5.1 Calculations for Material Removal Rate

The material removal rate is the rate of removal of material of workpiece by the tool measured in mm^3/min. For measuring the MRR we should know speed in m/min, feed rate in mm/revolution and depth of cut in mm.

Table 5.1 Calculation of MRR

Exp. No	Speed (RPM)	Speed (m/min)	Feed (mm/rev)	Depth of Cut (mm)	MRR(mm^3 /min)
1	300	15.07	0.1	0.2	301.44
2	300	15.07	0.2	0.4	1205.76
3	300	15.07	0.3	0.6	2712.96
4	450	22.61	0.1	0.4	904.32
5	450	22.61	0.2	0.6	2712.96
6	450	22.61	0.3	0.2	1356.48
7	600	30.14	0.1	0.6	1808.64
8	600	30.14	0.2	0.2	1205.76
9	600	30.14	0.3	0.4	3617.28

Material removal rate can be calculated by using the relation below

$$\textbf{Speed in}\,\frac{\textbf{m}}{\textbf{min}} = \textbf{Shaft Diameter (mm)x Speedin RPM x 0.001 x}\,\boldsymbol{\pi}$$

$$MRR = 1000 \times Speed\ in\frac{m}{min} \times feed\ in\frac{mm}{rev} \times depth\ of\ cut\ in\ mm$$

5.1.1 Calculation of S/N ratio for Material Removal Rate

The S/N ratio, which condenses the multiple data points within a trial, depends on the type of characteristics being evaluated. For calculation of S/N ratio for material removal rate LARGER IS BETTER condition is opted. The equation for the calculation of S/N ratio for material removal rate is:

$$S/N_{LB} = -10 \log \left(\Sigma \left(1/y_i^{2}\right) \right)$$

Table 5.2 Calculation of S/N ratio for MRR

S.No	MRR(mm^3/min)	Signal to noise ratio (db)
1	301.44	49.584
2	1205.76	61.6252
3	2712.96	68.6689
4	904.32	59.1264
5	2712.96	68.6689
6	1356.48	62.6483
7	1808.64	65.147
8	1205.76	61.6252
9	3617.28	71.1676

5.1.2 Calculation of Mean S/N ratio for Material Removal Rate

Mean S/N ratio is calculated by using following formula

$$\mathbf{nf_i = (nf_1+nf_2+nf_3)/3}$$

Where nf is mean S/N ratio for factor f at the level value i of the selected factor.
nf_1, nf_2, nf_3 are S/N ratio for factor f at level u

The factors which affect the machining parameters show in the table as their respective ranks. Rank of the parameters depends on the value of delta. If the delta value of one parameter is higher than the other that shows first rank. Higher value of S/N ratio of each factor shows the optimal level of the factor. Cutting speed is the least effective machining parameter for material removal rate while and feed and depth of cut are more effective.

Table 5.3 Calculation of mean S/N ratio for MRR

Level	**Speed**	**Feed**	**Depth of Cut**
1	59.96	57.95	57.95
2	63.48	63.97	63.97
3	65.98	67.49	67.49
Delta	6.02	9.54	9.54
Rank	**3**	**1.5**	**1.5**

5.1.3 Analysis of Variance for Material Removal Rate

The following table 5.4 depicts analysis of variance (ANOVA) for material removal rate. It shows that feed is the most crucial factor for material removal rate with a contribution of 40.99% while depth of cut is the second most dominating parameter with a contribution of 36.90%. It is also observed that cutting speed is the least influencing parameter for MRR and contributes only 11.40% towards it.

Table 5.4 ANOVA of MRR

Source	DOF	SS	Adj MS	F Value	Contribution
Speed	2	1014671	507336	1.06	11..40%
Feed	2	3649787	1824894	3.83	40.99%
Depth of Cut	2	3286323	1643161	3.44	36.90%
Error	2	954094	477047		10.71%
Total	8	8904875			100%

At least 95% confidence

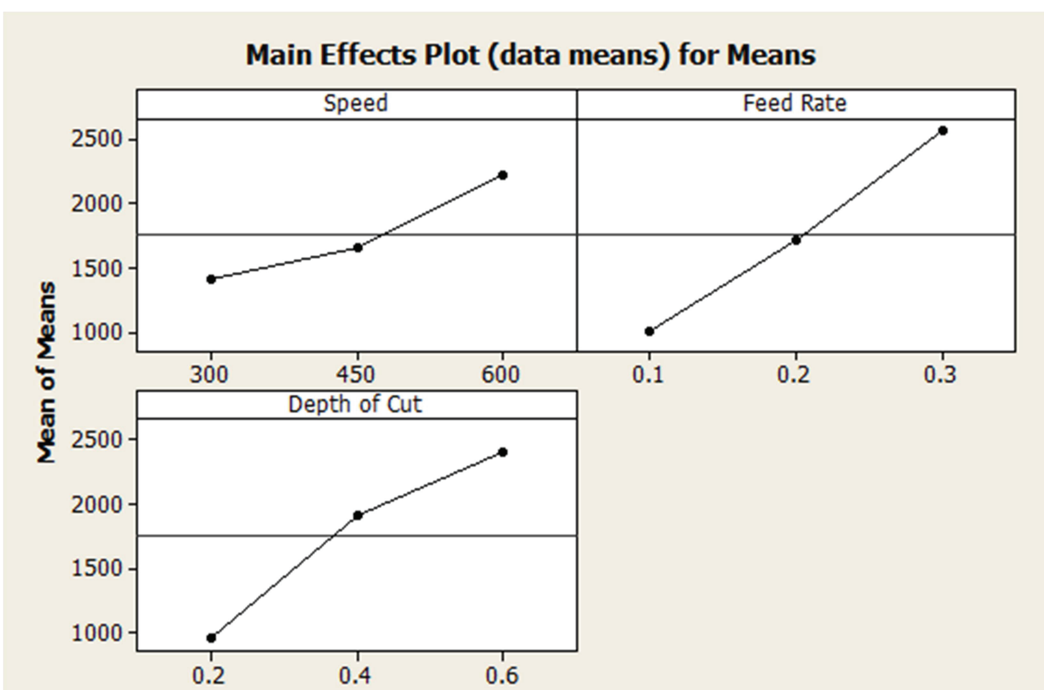

Figure 5.1 Main Effect Plot for MRR

From the graph on previous page it is clear that as we increase the machining parameters, the material removal rate increases. While considering feed rate and depth of cut, steep lines are observed. The MRR is majorly influenced by these two turning parameters as previously depicted by ANOVA. A less influencing rather flat curve is observed for cutting speed with MRR. As the cutting parameters increases, the material is removed at a faster rate and hence MRR increases. MRR increases with increase in feed and the graph obtained shows that MRR is majorly influenced by feed rate. As we increase the feed, the thickness of material to be removed increases. This reduces lead time and hence increases material removal rate. In case of depth of cut, as the level of depth of cut is increased, material removal is observed to get increased. Depth of cut is the distance of newly machined surface to the uncut surface. Thus as it is increased, the thickness of material to be removed increases and hence it will increase the material removal rate. It can be seen from the three graphs shown above that all the three machining parameters viz. cutting speed, feed per revolution and depth of cut directly affect the MRR and increases with the increase in value of parameters. Maximum MRR is obtained at 600 RPM speed, 0.3 mm feed rate and 0.6 mm depth of cut.

Optimal Levels of Parameters for Material Removal Rate

For MRR the optimal level of parameters are as follows

Table 5.5 Optimal level of parameter for MRR

Process variables of factors		**Optimum level**
Speed	**RPM**	600
Feed	**mm/rev**	0.3
Depth of Cut	**Mm**	0.6

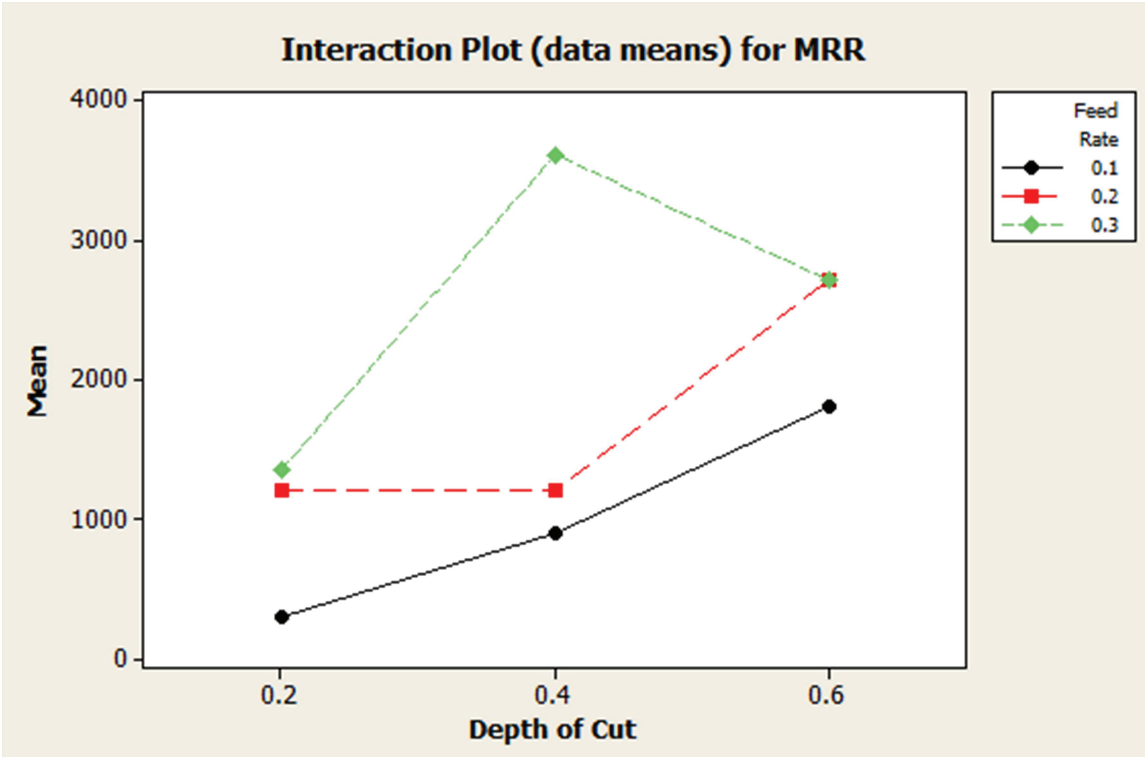

Figure 5.2: Interaction Plot between MRR and Plain turning parameters

The above Figure 5.2 shows the interaction of MRR with plain turning parameters. It is seen from the graph that at lower feed rate, the MRR increases almost linearly with increase in the level of depth of cut. At highest level of feed rate i.e. 0.3 mm/rev, the MRR initially increases with increase in depth of cut, but with further increase in value of depth of cut the MRR tends to decrease.

5.2 Calculations for Surface Roughness

The surface roughness of each machined sample was estimated by stylus type Talysurf surface profilometer. The machine surface was examined and the measure of surface roughness of each sample was jotted into a table in order to assess the influence of turning parameters on surface finish produced. The table 5.6 on the next page shows the values of surface roughness of each machined sample at varying with speed, feed and depth of cut.

Table 5.6: Calculation for Surface Roughness

Exp. No	Speed (RPM)	Feed (mm/rev)	Depth of Cut (mm)	Ra(µm)
1	300	0.1	0.2	6.13
2	300	0.2	0.4	6.62
3	300	0.3	0.6	6.88
4	450	0.1	0.4	7.11
5	450	0.2	0.6	7.52
6	450	0.3	0.2	6.77
7	600	0.1	0.6	7.41
8	600	0.2	0.2	6.96
9	600	0.3	0.4	7.82

5.2.1 Calculation of S/N ratio for Surface Roughness

The S/N ratio, which condenses the multiple data points within a trial, depends on the type of characteristics being evaluated. For calculation of S/N ratio for surface roughness SMALLER IS BETTER condition is opted. Smaller the surface roughness, better is the surface characteristics.

The equation for the calculation of S/N ratio for surface roughness is:

$$S/N_{SB} = -10 \log \left((1/n) \Sigma y_i^2 \right)$$

Table 5.7 Calculation of S/N ratio for Surface Roughness

S.No	Ra (µm)	Signal to noise ratio (db)
1	6.13	-15.7492
2	6.62	-16.4172
3	6.88	-16.7518
4	7.11	-17.0374
5	7.52	-17.5244
6	6.77	-16.6118
7	7.41	-17.3964
8	6.96	-16.8522
9	7.82	-17.8641

5.2.2 Calculation of Mean S/N ratio for Surface Roughness

The mean S/N ratio is calculated to assess the rank of the selected turning parameters that are influencing the surface roughness of the machined surface. It is calculated by using following formula

$$nf_i = (nf_1 + nf_2 + nf_3)/3$$

Where nf is mean S/N ratio for factor f at the level value i of the selected factor.
nf_1, nf_2, nf_3 are S/N ratio for factor f at level u.

Table 5.8 Calculation of mean S/N ratio for Surface Roughness

Level	Speed	Feed	Depth of Cut
1	-16.31	-16.73	-16.40
2	-17.06	-16.93	-17.11
3	-17.37	-17.08	-17.22
Delta	1.06	0.35	0.82
Rank	**1**	**3**	**2**

5.3.3 Analysis of Variance for Surface Roughness

ANOVA for surface roughness is given in the following table-

Table 5.9 ANOVA of Surface Roughness

Source	DOF	SS	Adj MS	F Value	Contribution
Speed	2	1.14562	0.57281	13.90	54.87%
Feed	2	0.11242	0.05621	1.36	5.38%
Depth of Cut	2	0.74736	0.37368	9.07	35.80%
Error	2	0.08242	0.04121		3.95%
Total	8	2.08782			100%

At least 95% confidence

The table 5.9 on the previous page shows the analysis of variance for surface roughness and it depicts that speed is the major dominating turning parameter for the roughness of the surface machined and contributes 54.87%. It is followed by depth of cut with a contribution of 35.80%. Feed rate is found to be the least influencing parameter with only 5.38% contribution towards surface roughness.

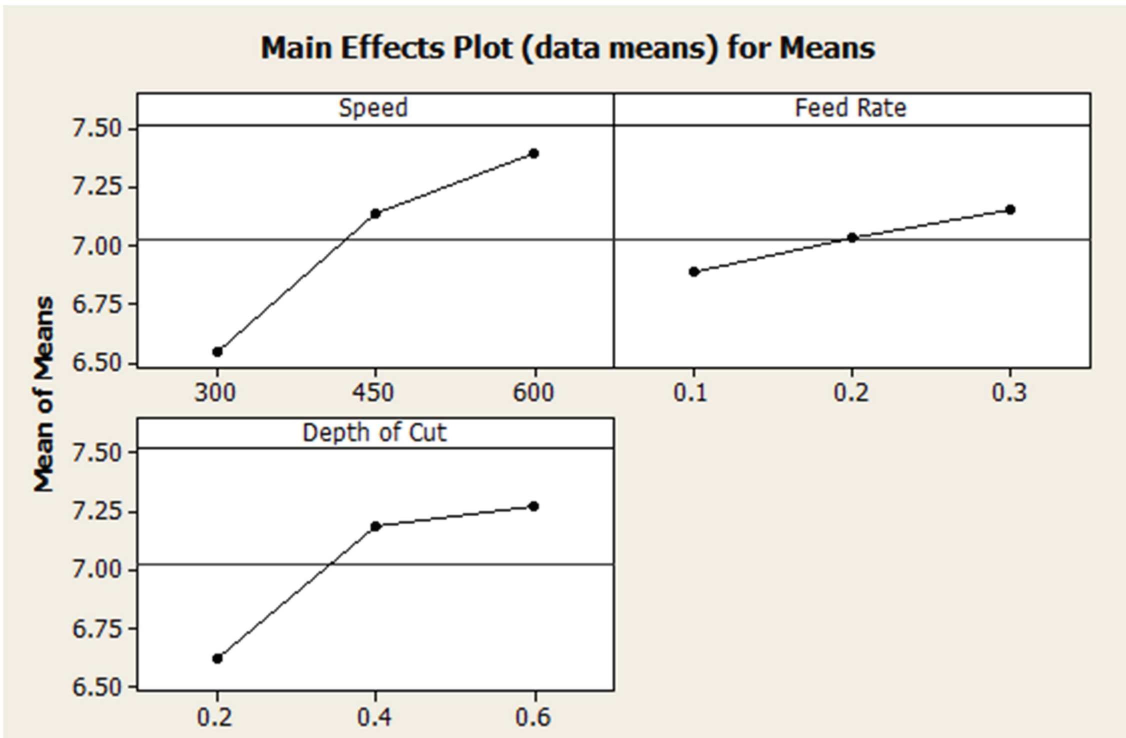

Figure 5.3 Main Effect Plot for Surface Roughness

The above graph shows the effect of input turning parameters on surface roughness. From all the three graphs it is seen that the surface finish degrades with increasing the level of turning parameters. By increasing the cutting speed the surface roughness increases and the surface finish starts to degrade. Very rough surface is generated as we increase the cutting speed to the higher levels. In case of feed rate, it also affects the surface roughness in similar fashion. The surface degrades with the increase in feed rate as thicker layer of material is removed which will roughen the new exposed machined surface. Increase in depth of cut also degrades the surface finish of EN-9. The most influential factor for surface roughness is the cutting speed followed by depth of cut and lastly by feed rate. Lowest surface roughness is obtained at 300 RPM cutting speed, 0.1 mm/rev feed rate and 0.2 mm depth of cut.

Optimal Levels of Parameters for Surface Roughness

For Surface Roughness the optimal level of parameters are as follows

Table 5.10 Optimal level of parameter for Surface Roughness

Process variables of factors		Optimum level
Speed	**RPM**	300
Feed	**mm/rev**	0.1
Depth of Cut	**Mm**	0.2

The graph in the Figure 5.4 below shows the relation and interaction between surface roughness produced and plain turning parameters. A similar pattern is seen in the case of surface roughness as that of the MRR. It is seen from the graph that at lower speed, the surface degradation increases almost linearly with increase in the level of depth of cut. At highest level of speed i.e. 600 RPM, the surface initially degrades more with increase in depth of cut, but with further increase in value of depth of cut the surface roughness tends to decrease.

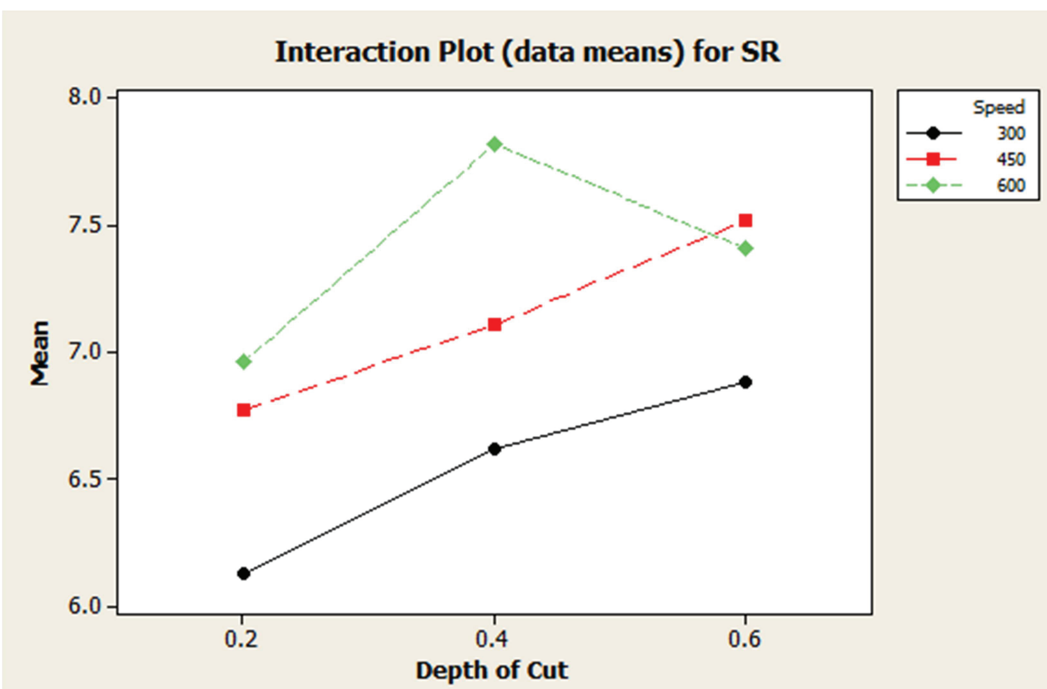

Figure 5.4: Interaction Plot between Surface Roughness and plain turning parameters

5.3 Confirmation Test

Confirmation tests have been performed for Material Removal Rate and Surface Roughness with their optimum levels of process variables.

Table 5.11: Confirmation of expected and actual values of MRR

Exp No.	Optimum Machining Parameters			MRR (gm/min)	
	Speed (RPM)	Feed (mm/rev)	Depth of Cut (mm)	Actual	Expected
1	600	0.3	0.6	3852.34	3656.29
				Error (%)	5.36%

Table 5.12: Confirmation of expected and actual values of Surface Roughness

Exp No.	Optimum Machining Parameters			Surface Roughness(μm)	
	Speed (RPM)	Feed (mm/rev)	Depth of Cut (mm)	Actual	Expected
1	300	0.1	0.2	6.13	6.52
				Error (%)	5.98%

6

CONCLUSION

CONCLUSION

This experimental study described the optimization of input machining parameters viz. cutting speed, feed rate and depth of cut in plain turning of EN-9 using L9 orthogonal array of Taguchi method. Factors with different levels were found to play significant role in plain turning operation for maximization of MRR and minimization of Surface Roughness.

Based on above work following conclusions are made:

- As we increase the machining parameters, the material removal rate increases. While considering feed rate and depth of cut, steep lines are observed. The MRR is majorly influenced by these two turning parameters as previously depicted by ANOVA.
- A less influencing rather flat curve is observed for cutting speed with MRR. As the cutting parameters increases, the material is removed at a faster rate and hence MRR increases. MRR increases with increase in feed and the graph obtained shows that MRR is majorly influenced by feed rate. As we increase the feed, the thickness of material to be removed increases. This reduces lead time and hence increases material removal rate.
- In case of depth of cut, as the level of depth of cut is increased, material removal is observed to get increased. Depth of cut is the distance of newly machined surface to the uncut surface. Thus as it is increased, the thickness of material to be removed increases and hence it will increase the material removal rate.

- It can be seen from the three graphs shown above that all the three machining parameters viz. cutting speed, feed per revolution and depth of cut directly affect the MRR and increases with the increase in value of parameters. Maximum MRR is obtained at 600 RPM speed, 0.3 mm feed rate and 0.6 mm depth of cut.
- Feed rate is the most crucial factor for material removal rate with a contribution of 40.99% while depth of cut is the second most dominating parameter with a contribution of 36.90%. It is also observed that cutting speed is the least influencing parameter for MRR and contributes only 11.40% towards it.
- By increasing the cutting speed the surface roughness increases and the surface finish starts to degrade. Very rough surface is generated as we increase the cutting speed to the higher levels.
- In case of feed rate, it also affects the surface roughness in similar fashion. The surface degrades with the increase in feed rate as thicker layer of material is removed which will roughen the new exposed machined surface.
- Increase in depth of cut also degrades the surface finish of EN-9. The most influential factor for surface roughness is the cutting speed followed by depth of cut and lastly by feed rate. Lowest surface roughness is obtained at 300 RPM cutting speed, 0.1 mm/rev feed rate and 0.2 mm depth of cut.
- Speed is the major dominating turning parameter for the roughness of the surface machined and contributes 54.87%. It is followed by depth of cut with a contribution of 35.80%. Feed rate is found to be the least influencing parameter with only 5.38% contribution towards surface roughness.

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LIST OF PUBLICATIONS

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Optimization of Turning Process Parameters in Machining Heat Treated Steel

by

Mohammad Shahid

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Good luck for your future endeavors

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