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ANALYSIS OF MACHINING PARAMETERS AND SURFACE ROUGHNESS OF Al6061 IN CNC TURNING CENTRE

A PROJECT REPORT

Submitted by

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BONAFIDE CERTIFICATE

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SYNOPSIS

Metal cutting is one of the most effective manufacturing processes in the area of material removal. Various surveys have shown that the correct cutting tool is selected less than 50% of the time , the tool is used at the rated cutting speed only 58% of the time , and only 38% of the tools are used up to their full tool life capability. The objective of this study is to develop a better understanding of the effects of spindle speed, cutting feed rate and depth of cut on the surface roughness and to build a multiple regression model for a CNC center with two interacting parameters that predicts the surface roughness values with an accuracy of about 12 %. In addition the cutting characteristics and optimal cutting conditions are found using Taguchi method in the design of experiments with the adaptation of L9 orthogonal array. Analysis of variance is performed in order to evaluate the effect of adjustment parameters on the quality features of the operation.

The parameters chosen to study the effect on surface roughness are , the cutting speed , the feed rate and the depth of cut . Limits for each of the parameters were set based on a thorough literature study and industrial consultation. The material selected is then machined for a set length in a CNC turning center after which the surface roughness of the machined length is measured in a surface roughness tester. The mathematical model is then generated based on these values and optimized to establish which parameter contributes to surface roughness.

It is found that the required surface finish could be obtained in a single run using hard turning and make unnecessary the post turning operation of grinding. Thus saving considerable amount of cost.

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CHAPTER 1
INTRODUCTION

Metal cutting is one of the most significant manufacturing processes in the area of material removal. It has been recognized that the reliable quantative predictions of the various technological performance measures, preferably in the form of equations, are essential to develop optimization strategies for selecting cutting conditions in process planning. The progress in the development of predictive models, based on cutting theory, has not yet met the objective when concerned with individual machines. The most important cutting performance measures such as tool life, cutting force, roughness of the machined surfaced, energy consumption etc. A recent survey in the USA showed that the correct cutting tool is selected less than 50% of the times, the tool is used at the rated cutting speed only 58% of the time and only 38% of the tools are used up to their full tool life capacity. The same result was also reported by the American aircraft industry showing that selected cutting speed is far below the optimal economic speeds.

The challenge of modern machining industries is mainly focused on the achievement of high quality, in terms of work piece dimensional accuracy, surface finish, economy of machining in terms of cost saving and increase the performance of the product with reduced environmental impact. Surface roughness plays an important role in many areas and is a factor of great importance in the evaluation of machining accuracy. Taguchi method is a powerful tool for the design of high quality system. It provides simple, efficient and systematic approach to optimize designs for performance and cost. Taguchi approach to design of experiment is easy to adopt and apply for users with limited knowledge of statistics, hence gained wide popularity in the engineering and scientific community.The aluminium alloys are used in a variety of engineering applications like structural, cryogenic, food processing, oil and gas process industries etc because of light weight and high tensile. Surface finish and roughness also affects several functional attributes of parts such as contact causing surface friction, wearing, light reflection, heat transmission, ability of distributing and holding a lubricant, load-bearing capacity, coating or resisting fatigue.

In Coimbatore there are many medium scale production industries that manufacture components made of aluminium alloys that are outscored by large manufacturing giant. In most case a moderate surface finish is required which can be obtained in a single machining

of optimizing techniques, the machining parameters are set in an unscientific and unproductive manner. This necessitates the industries to go in for an additional grinding operation, which is a waste of productive time and resource.

Our project is aimed at conducting our study in one of these industries in town: conduct a set of experiments to find the machining parameter and other noise factors that influence the gross surface roughness of the machined aluminium. The mathematical model can also be developed on conducting additional experiment in the same environment so that coherence is maintained in the entire study. This will give you the theoretical equation governing the entire turning operation.

The primary objective of our study:

1. To find the optimal machining parameters using taguchi technique by the employment of L9 orthogonal array.
2. To find the factor that most affected the surface roughness value.
3. To development, the mathematical model for the turning operation.
4. To determine the various noises (uncontrollable factors) that affects the gross surface roughness.
5. To determine the approximate cost that could be saved by employing the right cutting parameters.

CHAPTER 2
LITERATURE REVIEW

Application of Taguchi method in the optimization of cutting parameters for turning operations

Nickel-base super alloy Inconel 718 is a high-strength, thermal-resistant. Because of its excellent mechanical properties, it plays an important part in recent years in aerospace, petroleum and nuclear energy industries. Due to the extreme toughness and work hardening characteristic of the alloy, the problem of machining Inconel 718 is one of ever-increasing magnitude. This investigation optimized the machining characteristics of Inconel 718 bars using tungsten carbide and cermet cutting tools. The approach is based on Taguchi method, the signal-to-noise (S/N) ratio and the analysis of variance (ANOVA) are employed to study the performance characteristics in turning operations. The roundness and flank wear of the ultrasonically and conventionally machined work pieces were measured and compared. Through this study, the optimal cutting parameters for turning operations can be obtained.

Guey-Jiuh Tzou , Ding-Yeng Chen, Chun-Yao Hsu

Optimization of Surface Roughness in End Milling on Mould Aluminium Alloys (AA6061-T6) Using Response Surface Method and Radian Basis Function Network

This paper is concerned with optimization of the surface roughness when milling Mould Aluminium alloys (AA6061-T6) with carbide coated inserts. Optimization of milling is very useful to reduce cost and time for machining mould. The approach is based on Response Surface Method (RSM) and Radian Basis Function Network (RBFN). RBFN was successfully used by Tsoa and Hocheng in their recent research. They used this network to predict thrust force and surface roughness in drilling. In this work, the objectives are to find the optimized parameters, and to find out the most dominant variables (cutting speed, federate, axial depth and radial depth). The first order model and RBFN indicates that the feed rate is the most significant factors effecting surface roughness. RBFN predicts surface roughness more accurately when compared to RSM.

K.Kadirgama, M.M.Noor, N.M.Zuki.N.M, M.M. Rahman, M.R.M. Rejab, R. Daud, K.

Prediction of Surface Roughness in CNC Turning Operation using Taguchi Design of Experiments

This paper outlines the Taguchi optimization methodology, which is applied to optimize cutting parameters in turning when machining hardened steel AISI 4140 with carbide insert tool under semi finishing and finishing conditions of high-speed cutting. All the experimental work has been conducted on CNC lathe at Kaizen Machine Tools, Faridabad, Haryana. The experiments carried out by using L-27 (313) orthogonal array. The turning parameters evaluated are, cutting speed, feed rate and depth of cut. An orthogonal array, signal-to-noise (S/N) ratio and Pareto analysis of variance (ANOVA) are employed to analyze the effect of these turning parameters on surface roughness. Main effects of process parameters on the quality characteristics have been analyzed and the results show that the optimum parameter setting for surface roughness is obtained at a cutting speed of 200 m/min, feed rate 0.1 mm/rev and depth of cut 1.5 mm and the optimum parameter setting for force required is obtained at a cutting speed of 200 m/min, feed rate 0.1 mm/rev and depth of cut 1 mm. Confirmation tests with the optimal levels of cutting parameters are carried out in order to illustrate the effectiveness of Taguchi optimization method. Using Taguchi method for design of experiment (DOE), other significant effects, such as, the interaction among turning parameters are also investigated.

A Jayant, V Kumar

Optimizing feed force for turned parts through the Taguchi Technique

The objective of the paper is to obtain an optimal setting of turning process parameters (cutting speed, feed rate and depth of cut) resulting in an optimal value of the feed force when machining EN24 steel with TiC-coated tungsten carbide inserts. The effects of the selected turning process parameters on feed force and the subsequent optimal settings of the parameters have been accomplished using Taguchi's parameter design approach. The results indicate that the selected process parameters significantly affect the selected machining characteristics. The results are confirmed by further experiments.

Hari singh and Pradeep kumar

A Study of the Effects of Machining Parameters on the Surface Roughness

A set of experiments designed to begin the characterization of surface quality for the end-milling process have been performed. The objective of this study is to develop a better understanding of the effects of spindle speed, cutting feed rate and depth of cut on the surface roughness and to build a multiple regression model. Such an understanding can provide insight into the problems of controlling the finish of machined surfaces when the process parameters are adjusted to obtain a certain surface finish. The model, which includes the effect of spindle speed, cutting feed rate and depth of cut, and any two variable interactions, predicted the surface roughness values with an accuracy of about 12%.

Mohammed T. Hayajneh a, Montasser S. Tahat , Joachim Bluhm

Analyses of surface roughness by turning process using Taguchi method

The purpose of this research paper is focused on the analysis of optimum cutting conditions to get lowest surface roughness in turning SCM 440 alloy steel by Taguchi method. Experiment was designed using Taguchi method and 18 experiments were designed by this process and experiments conducted. The results are analyzed using analysis of variance (ANOVA) method. Taguchi method has shown that the depth of cut has significant role to play in producing lower surface roughness followed by feed. The Cutting speed has lesser role on surface roughness from the tests .The vibrations of the machine tool, tool chattering are the other factors which may contribute poor surface roughness to the results and such factors ignored for analyses .The results obtained by this method will be useful to other researches for similar type of study and may be eye opening for further research on tool vibrations, cutting forces etc.

S. Thamizhmanii*, S. Saparudin, S. Hasan

A parameter design study in a turning operation using the Taguchi method

Modern manufacturers, seeking to remain competitive in the market, rely on their manufacturing processes for new products. Taguchi Parameter Design is a powerful and efficient method for optimizing quality and performance output of manufacturing processes, thus a powerful tool for meeting this challenge. This paper discusses an investigation into the use of Taguchi Parameter Design for optimizing surface roughness generated by a CNC turning operation. This study utilizes a standard orthogonal array for determining the optimum turning parameters, with an applied noise factor. Controlled factors include spindle speed, feed rate, and depth of cut; and the noise factor is slightly damaged jaws. The noise factor is included to increase the robustness and applicability of this study. After experimentally turning sample work pieces using the selected orthogonal array and parameters, this study produced a verified combination of controlled factors and a predictive equation for determining surface roughness with a given set of parameters.

E. Daniel Kirby

GA based CNC turning center exploitation process parameters optimization

This paper presents machining parameters (turning process) optimization based on the use of artificial intelligence. To obtain greater efficiency and productivity of the machine tool, optimal cutting parameters have to be obtained. In order to find optimal cutting parameters, the genetic algorithm (GA) has been used as an optimal solution finder. Optimization has to yield minimum machining time and minimum production cost, while considering technological and material constrains.

Z. CAR, B. BARISIC, M. IKONIC

Genetic algorithm-based multi-objective optimization of cutting parameters in turning processes

Determination of optimal cutting parameters is one of the most important elements in any process planning of metal parts. This paper presents a multi-objective optimization technique, based on genetic algorithms, to optimize the cutting parameters in turning processes: cutting depth, feed and speed. Two conflicting objectives, tool life and operation time, are simultaneously optimized. The proposed model uses a micro genetic algorithm in order to obtain the non-dominated points and build the Pareto front graph. An application sample is developed and its results are analyzed for several different production conditions. This paper also remarks the advantages of multi-objective optimization approach over the single objective one.

Ramón Quiza Sardiñas, Marcelino Rivas Santana, Eleno Alfonso Brindis

A study on the optimal cutting condition of a high speed feeding type laser cutting machine by using Taguchi method

Cutting by a high speed laser cutting machine is one of most effective technologies to improve productivity. This paper has presented the cutting characteristics and optimal cutting conditions in a high speed feeding type laser cutting machine by using Taguchi method in the design of experiment. An L9 (34) orthogonal array is adopted to study the effect of adjustment parameters. The adjustment parameters consist of cutting speed, laser power, laser output duty and assistant gas pressure. The surface roughness of sheet metal is regarded as a quality feature. Analysis of variance is performed in order to evaluate the effect of adjustment parameters on the quality feature of laser cutting process.

Sang-Heon Lim, Choon-Man Lee and Won Jee Chung

CHAPTER 3

TURNING

Turning is the process whereby a single point cutting tool is parallel to the surface. It can be done manually, in a traditional form of lathe, which frequently requires continuous supervision by the operator, or by using a computer controlled and automated lathe which does not. This type of machine tool is referred to as having computer numerical control, better known as CNC , and is commonly used with many other types of machine tool besides the lathe.

When turning, a piece of material (wood, metal, plastic even stone) is rotated and a cutting tool is traversed along 2 axes of motion to produce precise diameters and depths. Turning can be either on the outside of the cylinder or on the inside and produce tubular components to various geometries. Although now quite rare, early lathes could even be used to produce complex geometric figures, even the platonic solids; although until the advent of CNC it had become unusual to use one for this purpose for the last three quarters of the twentieth century. It is said that the lathe is the only machine tool that can reproduce itself.

The turning processes are typically carried out on a lathe, considered to be the oldest machine tools, and can be of four different types such as straight turning , taper turning , profiling or external grooving . Those types of turning processes can produce various shapes of materials such as straight, conical, curved, or grooved work piece . In general, turning uses simple single-point cutting tools. Each group of work piece materials has an optimum set of tools angles which have been developed through the years.

3.1 HARD TURNING

Since the late 1970's the turning of material with hardness greater than 35HRC, has become economically, environmentally, and technically viable. Hard turning is a competitive finishing process for manufacturing precision mechanical components . The hard turning process is similar enough to conventional turning that the introduction of this process into the normal factory environment can happen with relatively small operational changes when the proper elements have been addressed.

Hard turning is best accomplished with cutting inserts made from carbide inserts. Since hard turning is single point cutting, a significant benefit of this process is the capability to produce contours and to generate complex forms with inherent motion capability of configured machine tool and the appropriate tooling. For many applications, Carbide tooling will be the most dominant choice. However, ceramic and cermets also have roles in this process. The range of applications for hard turning varies widely, where in some cases hard turning serves as a grinding replacement process and can also be quite effective for pre-grinding preparation processes. The attractiveness of the process lies in the performance numbers. Hard turning is a technology-driven process that requires certain performance features of the machine tool, work holding, process and the tooling.

3.2 APPLICATIONS

Hard turning can be certainly considered for most pre-grinding applications which are followed by an abbreviated grinding cycle. In some cases the hard turned surface may complete the operation and will completely eliminate the grinding cycle.

Hard turning is an important technology because all manufactures are continually seeking ways to manufacture their parts with lower cost, higher quality, rapid setup, lower investments, smaller tooling inventory and the elimination off non-value added activities. The migration of processing from grinders to lathes can satisfy each and every one of those goals.

Hard turning finds application in the following industrial segments, automotive, bearing, marine, punch and die, mould hydraulics and pneumatics, machine tool and aerospace.

The typical materials which are routinely hard turned include those of the following broad category descriptions:

- Steel alloys
- Bearing steels
- Hot and cold work tool steel
- High speed steels
- Die steels
- Case hardened steels
- Waspoloy , stellite and other aerospace alloys
- Nitrated irons and hard chrome coatings
- Heat treatable powdered metallurgy

An important aspect in hard turning is surface integrity, because there is need to design a machining process for optimal surface integrity to maximize component life in service. Hard turning may induce a deep compressive residual stress in the subsurface, while it may also produce a phase-transformed layer of material on the component surface, commonly referred to as white layer of its white appearance under an optical microscope.

The white layer is harder than the bulk-material, and is often associated with tensile residual stresses. It is often assumed that a white layer is determined to fatigue life though its effect on service life is poorly understood. In hard turning selection of appropriate cutting tool and machinery is necessary.

3.3 ADVANTAGES OF HARD TURNING

- Smaller space requirement
- Turned diameters are rounder than ground diameters
- Heat dissipates in chip during turning
- Higher metal removal rates
- Low micro finishes
- No expensive coolant is needed
- Less down time for tool changes
- Increased service life of hard turned components due to better geometry, untempered martensite layers and surface compressive residual stress.

3.4 FACTORS INFLUENCING HARD TURNING PROCESS

The factors that influence the hard turning process can be categorized as

- Machine technology
- Process technology
- Materials and tooling technology
- Work holding technology

Rigidity is critical for successful hard turning, the rigidity of tooling, work holding, and the machine tool are the crucial elements that will affect the ability to successfully hard turn .In hard turning, it is well –established that the presence of vibration is not desirable for multiple standpoints. A machine which has improved damping will demonstrate the improvements in lowering the amplitude of vibration and the time to decay, all while maintaining the static toughness. The real and measurable results are longer tool life better surface finishes, improved accuracy, improved productivity and higher overall product

CHAPTER 4

THEORY OF METAL CUTTING

Turning is one of the metal cutting processes, so to understand the different parameters that affect the machining operation we have to be aware of the basic of metal cutting. The following chapter gives you an overview the turning process

4.1 THE MECHANISM OF CUTTING

· Assuming that the cutting action is continuous we can develop a continuous model of cutting conditions.

· Orthogonal Cutting - assumes that the cutting edge of the tool is set in a position that is perpendicular to the direction of relative work or tool motion. This allows us to deal with forces that act only in one plane.

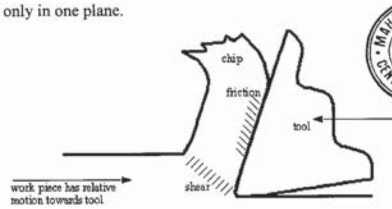


Fig 4.1 Orthogonal cutting

· We can obtain orthogonal cutting by turning a thin walled tube, and setting the lath bit cutting edge perpendicular to the tube axis.

· Next, we can begin to consider cutting forces, chip thicknesses, etc.

where,

t_1 = undeformed chip thickness
t_2 = deformed chip thickness (usually $t_2 > t_1$)
α = tool rake angle

If we are using a lathe, t_1 is the feed per revolution

Next, we assume that we are also measuring two perpendicular cutting forces that are horizontal, and perpendicular to the figure above. This then allows us to examine specific forces involved with the cutting. The cutting forces in the figure below (Fc and Ft) are measured using a tool force dynamometer mounted on the lathe.

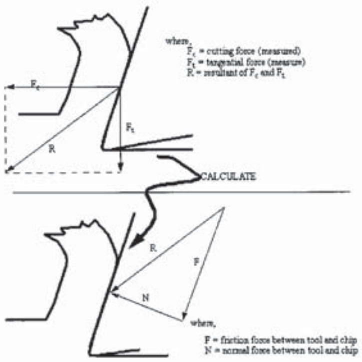


Fig 4.3 Cutting forces

4.2 CHIP FORMATION

· There are three types of chips that are commonly produced in cutting,

1. - discontinuous chips
2. - continuous chips
3. - continuous with built up edge

· A discontinuous chip comes off as small chunks or particles. When we get this chip it may indicate,

1. - brittle work material
2. - small rake angles
3. - coarse feeds and low speeds

· A continuous chip looks like a long ribbon with a smooth shining surface. This chip type may indicate,

1. - ductile work materials
2. - large rake angles
3. - fine feeds and high speeds
4. - use of coolant and good chip flow

· Continuous chips with a built up edge still look like a long ribbon, but the surface is no longer smooth and shining. This type of chip tends to indicate, high friction between work and tool causes high temperatures that will occasionally weld the chip to the tool. This will break free, but the effects are a rough cutting action.

· Continuous chips, and subsequently continuous cutting action is generally desired.

4.3 TEMPERATURES IN CUTTING

· There are three main sources of heat when cutting,

1. 1. Heat is produced as the tool deforms (works) the metal
2. 2. Friction on the cutting face
3. 3. Friction on the tool flank

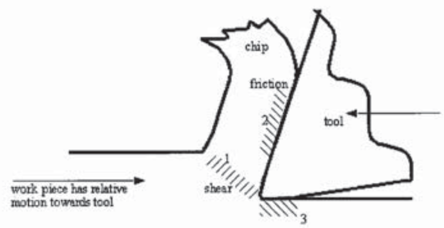


Fig4.4 Temperature in the cutting zone

· Heat is mostly dissipated by,

1. 1. The discarded chip carries away heat
2. 2. Coolant will help draw away heat
3. 3. The work piece acts as a heat sink
4. 4. The cutting tool will also draw away heat.

4.4 TOOL WEAR

· Tool wear is still a significant problem in cutting.

· Typical types of tool wear include,

1. - Flank wear
2. - Crater wear

· Flank wear - the point of the tool degrades

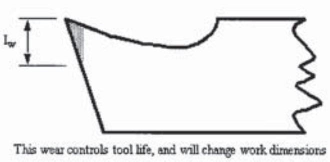


Fig4.5 Cutting tool

· Crater wear also decreases tool life

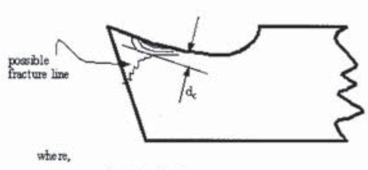


Fig 4.6 Tool wear

· Tool failure can typically grouped under one of the following categories,

1. - Complete Failure - the tool is unusable
2. - Flank Failure - this can be estimated with maximum lw values,
   1· Roughing Cuts
   - 0.03" for carbide tools
   - 0.06" for high speed steel
   - 0.010" for carbides
   - 0.015" for high speed steel
3. - Work surface finish is inadequate
4. - Work dimension outside tolerance

· Flank wear can be discussed as a function of time,

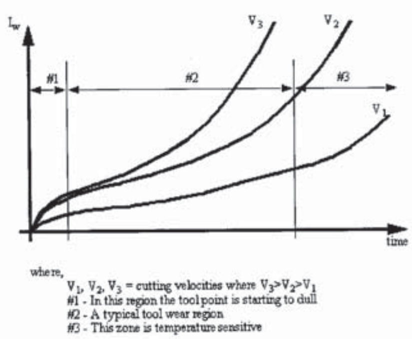


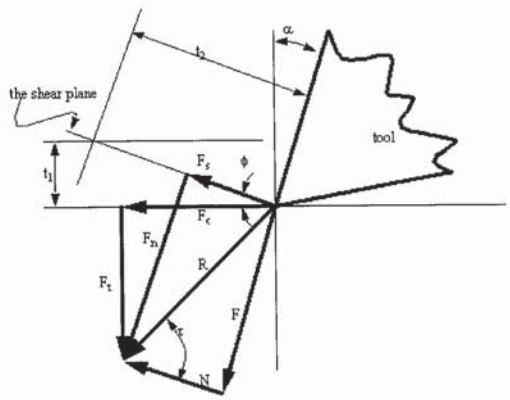
Fig 4.7 Tool wear as a function of time

· General notes of concern are,

1. - The main factor in tool wear is temperature
2. - The main factor in tool life is cutting speed
3. - Critical temperatures for High Speed Steels are 1150°F and for carbides it is 1600°F
4. - A higher velocity will increase temperature more than an increase in feed for the same
5. - A higher feed will increase the tool forces

4.5 FORCE CALCULATIONS

· The forces and angles involved in cutting are drawn below,



F_s = shear force
F_n = force normal to shear plane
α = tool rake angle (positive as shown)
ϕ = shear angle
τ = friction angle

Fig 4.8 Force calculations

Having seen the vector based determination of the cutting forces, we can now look at the equivalent calculations

$$\frac{F}{N} = \tan\tau = \mu$$

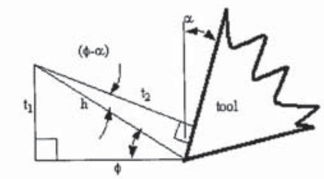
where,

μ = the coefficient of friction

$$r_c = \frac{t_1}{t_2}$$

where,

r_c = the cutting ratio



$$t_1 = h\sin\phi \qquad t_2 = h\cos(\phi - \alpha)$$

$$r_c = \frac{t_1}{t_2} = \frac{h\sin\phi}{h\cos(\phi-\alpha)} = \frac{\sin\phi}{\cos\phi\cos\alpha + \sin\phi\sin\alpha}$$

$$\therefore r_c\cos\phi\cos\alpha + r_c\sin\phi\sin\alpha = \sin\phi$$

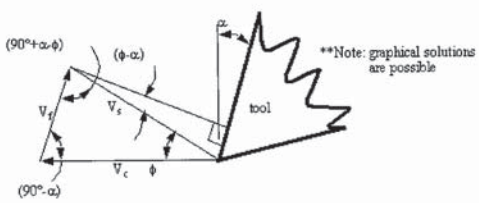
$$\therefore \frac{r_c\cos\phi\cos\alpha}{\sin\phi} + \frac{r_c\sin\phi\sin\alpha}{\sin\phi} = 1$$

$$\therefore \frac{r_c\cos\alpha}{\tan\phi} = 1 - r_c\sin\alpha$$

$$\therefore \tan\phi = \frac{r_c\cos\alpha}{1 - r_c\sin\alpha}$$

· The velocities are also important, and can be calculated for later use in power calculations. The Velocity diagram below can also be drawn to find cutting velocities.

And, by trigonometry,



where,

V_c = cutting velocity (ft./min.) - as set or measured on the machine
V_s = shearing velocity
V_f = frictional velocity

Using the sine rule,

$$\frac{V_s}{\sin(90° - \alpha)} = \frac{V_c}{\sin(90° + \alpha - \phi)}$$

$$\therefore V_s = \frac{V_c\sin(90° - \alpha)}{\sin(90° + \alpha - \phi)} = \frac{V_c\cos\alpha}{\cos(\phi - \alpha)}$$

Also,

$$V_f = \frac{V_c\sin\phi}{\cos(\phi - \alpha)}$$

Fig 4.9 Cutting velocities

· A final note of interest to readers not completely familiar with vectors, the forces Fc and Ft, are used to find R, from that two other sets of equivalent forces are found.,

$$R = \sqrt{F_c^2 + F_t^2} = \sqrt{F_s^2 + F_n^2} = \sqrt{F^2 + N^2}$$

CHAPTER 5
TAGUCHI TECHNIQUE

5.1 INTRODUCTION

One method presented in this article is an experimental design process called the Taguchi method. Similar to DOE, the Taguchi method is a technique for optimizing a process or design using multiple parameters. A researcher should always fully understand the various experimental methods in order to properly apply them to individual studies to maximize both the efficiency and the result of a study. The complete Taguchi methods are actually comprised of three main phases, which are all intended to be conducted offline. These three phases include system design, parameter design, and tolerance design. The Taguchi parameter design stage, which is the phase used in study, is commonly referred to here. This phase requires that the factors are known ant that production should be in progress. The major goal of this phase is to increase the performance of the production process by adjusting the controlled factors.

5.2 THE PURPOSE OF EXPERIMENTATION

The purpose of product or process development is to improve the performance characteristics of the product or process relative to customer needs and expectations. The purpose of experimentation should be to understand how to reduce and control variation of a product or process; subsequently, decisions must be made concerning which parameters affect the performance of a product or process.

A matrix experiment consists of a set of experiments where the settings of several product or process parameters to be studied are changed from one experiment to another. Matrix experiments are also called design experiments, parameters are also called factors, and the parameter settings are also called levels.

There are two methods in conducting experiments.

1. Full factorial experimental design.(Design of Experiments technique)
2. Fractional factorial experimental design.(Taguchi technique)

In full factorial technique all possible combinations of the inputs will be included in experiment. But in Fractional factorial experimental design a smaller number of combinations is sufficient. The following table shows the difference between these two designs.

Table 5.1 Comparison between Taguchi and DOE methodology

	Design of Experiments Technique	Taguchi technique
Process Knowledge	Assumes no fundamental understanding of the process being investigated	Requires knowledge of the process and the interactions likely to exist between inputs
No of Tests	Requires all combinations of inputs	Requires a much smaller number of combinations
Noise Factors	Traditionally ignores noise factors, but they can be added to the plan(which cause the number of tests to multiply)	Includes the noise factors in the design
Variability	Ignores variability and assumes a deterministic nature of the system to find the most effective combinations of inputs to maximize output	Assumes a stochastic system, looking at both levels and variability of the output to allow the selection of input variable combinations to optimize output or minimize variability
Confirmation Experiment	Does not require a confirming experiment, since all input combinations were tested	Should include a confirming experiment, because the selected input combination were probably not part of the original experimental plan.

Conducting matrix experiments using orthogonal arrays is an important technique in robust design. It gives reliable estimates of factor effects with fewer experiments when compared to traditional methods such as one factor at a time experiments. Consequently, more factors can be studied within the available resources, leading to more robust and less expensive products.

5.3 DEFINITION OF A DESIGNED EXPERIMENT

A designed experiment is the simultaneous evaluation of two or more factors parameters for the ability to affect the resultant average or variability of particular product or levels of factors are varied in a strategic manner, the results of the particular test combinations are observed, and the complete set of results is analyzed to determine the influential factors and preferred levels.

5.4 THE DESIGN OF EXPERIMENTS PROCESS

The DOE process is divided into three main phases which encompasses all experimentation approaches. The three main phases are

1. Planning phase
2. Conducting phase
3. Analysis phase

5.5 PLANNING PHASE

The planning phase is when factors and levels are selected and therefore, is the most important stage of experimentation. If the real influential factors and levels are selected the experiment results will result in positive information is an indication of which factors and which levels lead to improved product or process performance. If not, experiment will result in identifying negative information that is, which levels will not lead to improved product or process performance. The planning phase includes the following steps,

1. State the problems or areas of concern.
2. State the objectives of the experiment.
3. Select the quality characteristics and measurement system.
4. Select the factors that may influence the selected quantity characteristics and measurement systems.
5. Identify control and noise factors.
6. Select levels for the factors.
7. Select the appropriate orthogonal array (OA).
8. Select interactions that may influence the selected quality characteristics.
9. Assign factors to OA and locate interactions.

5.5.1 Problem statement and objective

Cutting forces has been one of the most important quality measures in many mechanical products. Thus an attempt is made to obtain an optimal setting of turning process parameters (cutting speed, feed rate, and depth of cut) resulting in an optimal value of surface finish when machining MARAGING STEEL with CARBIDE INSERTS.

5.5.2 Selection of control factors

The control factors can be identified using different tools. One of those tools is cause and effect diagram provided by ishikawa. The C-E diagram to obtain quality parts in turning is constructed in fig

5.5.3 Selection of levels for the factors

To perform this step following information is needed,

- A list of control and noise factors
- Product or process technical expertise
- Product or process specification or operating limits

A minimum of two levels are required to evaluate a factors effect on a giving quality characteristic. In the beginning round more number of factors can be included with reduced levels so that the size of the experiments will be minimized. After finding the influential factors through the first round, levels can be increased to optimize the response.

The selection of parameters of inserts was based on some preliminary experiments and from literature survey. The selected parameters with their levels are listed in table

Table 5.2 Factors and Level tabulation

	Factors/parameters name	Level 1	Level 2	Level 3
A	Cutting speed (m/min)	225	330	350
B	Feed (mm/rev)	.05	.075	1
C	Depth of cut (mm)	1	2	3

The following parameters were kept fixed during the entire experiment.

1. Work piece material	:	Al 6061
2. Work piece condition	:	100 mm length.
3. Insert geometry	:	CCMT 21.51 Insert
4. Insert material	:	Tungsten Carbide
5. Cutting condition	:	Dry

5.5.4 Types of factors

a) Signal factors

These factors specify the intended value of product response.

Noise factors: factors that cannot be controlled by the designer are termed as noise factors .Factors whose settings are difficult or expensive to control are also called noise factors. The noise factors themselves can be divided into three broad classes.

- External (environmental and load factors)
- Unit to unit variation (manufacturing non-uniformity)
- Deterioration (wear-out , process drift)

b) Control factors

Factors that can be specified by the designer are under the category of control factors. Their settings are selected to minimize the sensitivity of the products response to all noise factors.

5.5.5 Orthogonal arrays

In this stage one has to decide whether to go for a full factorial or fraction

Factorial experiments. A full-factorial experiment is acceptable when only a few factors are to be investigated, but not very acceptable when there are many factors. If a full-factorial experiment is used, there is a minimum of 2f possible combinations that must be tested (f=the number of factors each at two levels)

The selection of which OA to use predominantly depends on these items in order of priority:

1. The number of factors and interactions of interest
2. The number of levels for the factors of interest
3. The desired experimental resolution or cost limitations.

5.5.6 Types of Orthogonal Arrays

Two basic kinds of OA's are available. When all factors involved have 2- levels the available arrays are L4, L8, L12, L16, L32. Similarly for 3-level the available arrays are L9, L18, L27. The number in the array designation indicates the number of trails (different possible test combinations) in the array; an L8 has eight trials and L27 has 27 trials, for example. A factor

OA designate the appropriate level of the factor assigned to that column to be used for that specific trial. The following table given will be helpful in selecting orthogonal arrays for the particular situation.

Table 5.3 Orthogonal array

Orthogonal array	Number of rows	Maximum number of factors	Maximum number of columns of these levels			
			2	3	4	5
L4	4	3	3	-	-	-
L8	8	7	7	-	-	-
L9	9	4	-	4	-	-
L12	12	11	11	-	-	-
L16	16	15	15	-	-	-
L16	16	5	-	-	5	-
L18	18	8	1	7	-	6
L25	25	6	-	-	-	-
L27	27	13	-	13	-	-
L32	32	31	31	-	-	-
L32	32	*10	1	-	9	-
L36	36	23	11	12	-	-
L36	36	16	3	13	-	-
L50	50	12	1	-	-	11
L54	54	26	1	25	-	-
L64	64	63	63	-	-	-
L64	64	21	-	-	21	-
L81	81	40	-	40	-	-

Interaction effect of factors

Pairs of factors in an experiment may interact with one another to provide a synergistic effect on a quality characteristic being studied. A typical interaction plot appears in the figure. The

level, the B effect appears to be relatively small and at the A2 level, the B effect appears to be relatively large. Similarly B's effect depends upon which level of factor A was being used. This mutual dependency between the factors is an interaction of those factors when a two factor experiment is conducted; there are three items that may be statistically estimated:

1. Factor A's overall effect to change the result
2. Factor B's overall effect to change the result
3. The interaction effect of factors A and B to change the result

   Statistically, these are treated as three separate items which may have their individual strengths estimated.

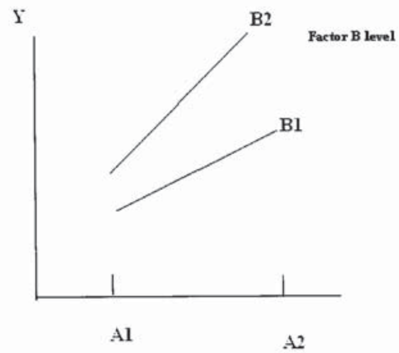


Fig 5.1 Model interaction graph

5.5.8 Assignment of factors and location of interactions

Orthogonal arrays have several columns available for the assignment of factors and some columns will, subsequently, estimate the effect of interaction of those factors. In orthogonal arrays, if one factor is assigned to any other particular column, a specific third column will automatically have the interaction of those factors assigned to that column. The pattern of which columns will be interaction columns is known for all of the orthogonal

Table 5.4 Factors and location of interactions

Column	2	3	4
1	3,4	2,4	2,3
2	-	1,4	1,3
3	-	-	1,2

If factor A is assigned at column1 and factor B is assigned at column 2, from the table we can see that the interaction will be assigned at column 3 or 4.

5.5.9 Resolution of experiments

In Taguchi technique, sometimes many interactions are confounded (mixed) with the main effects. This is the major compromise of using Taguchi technique to reduce the number of tests, some information must be surrendered. By selecting correct OA we can reduce the confounding which occurs between main effects and interactions. But Taguchi views interactions as being of minimal interest because to utilize the interactive effect the experimenter must control two main effects. Since one or more main effects usually need to be controlled for a product or process anyway, the interaction causes no additional complications.

5.5.10 Selection of orthogonal array

Speed, feed rate and depth of cut and are the parameters selected in this work. It was decided to study only the main effects. The number of levels used in the factors should be used to select either two level or three level types of OA's. The nonlinear relationship among the process parameters, if it exists, can only be revealed if more than two levels of the parameters are considered. Thus each selected parameters are considered. Thus each selected parameters was analyzed at three levels. Hence we have to select arrays from 3- level orthogonal arrays.

It was decided to study only the main effects because the interactions are minimal interest. The total degrees of freedom (DOF) for three parameters, each at three levels, are six (Ross 1996). So, a three level OA with at least nine DOF has to be selected. The L9 OA (DOF=8) was thus selected for the present case study. The L9 OA is given in table below. This array specifies nine experimental runs and has four columns. Speed, feed, DOC are

Orthogonal Array for L9

Table 5.5 L9 orthogonal array

S.NO.	Cutting Speed (m/min)	Feed (mm/rev)	Depth of cut (mm)
1.	1	1	1
2.	1	2	2
3.	1	3	3
4.	2	1	2
5.	2	2	3
6.	2	3	1
7.	3	1	3
8.	3	2	1
9.	3	3	2

CHAPTER 6

EXPERIMENTAL METHODOLOGY

6.1 INTRODUCTION

The second phase of design of experiments is conducting phase. In conducting phase experiment are conducted for the selected process parameter combinations at a random order. The conducting phase involves the following tasks.

1. Preparation of work piece
2. Procurement of insert
3. Conducting experiments
4. Measuring surface roughness
5. Measuring cutting forces.

6.2 WORK MATERIAL PREPARATION

The work material is Aluminium Al6061. The different properties such as physical, mechanical thermal properties and composition of Al6061 are given below.

Table 6.1 Composition of Al6061

Component	Wt %
Al	95.8 -98.6
Cr	0.04 – 0.35
Cu	0.15 – 0.4
Fe	Max 0.7
Mg	0.8 – 1.2
Mn	Max 0.15
Si	0.4 – 0.8
Ti	Max 0.15
Zn	Max 0.25
Other each	0.05
Other total	0.15

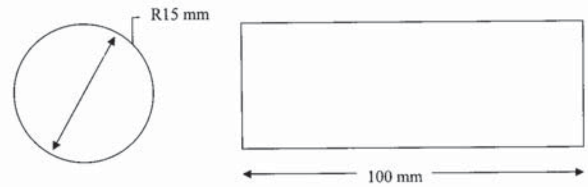


Fig 6.1 Work material specification

Physical Properties:

Density : 2.7 g/cc

Mechanical Properties

Brinell Hardness : 30
Ultimate Tensile strength : 124 Mpa
Yield Tensile Strength : 55.2 Mpa
Elongation at Break : 25 %
Shear modulus : 26 GPa
Poisson's ratio : 0.33
Fatigue strength : 62.1 MPa
Machinability : 30 %
Ultimate bearing strength : 228 MPa
Yield hearing strength : 103 MPa
Modulus of Elasticity : 68.9 Gpa

Thermal Properties

CTE,Linear (250 0 C) : 25.4 µm/m-°C
Melting Point : 582 - 652 °C
Heat Capacity : 0.896 J/g-°C
Solidus : 582°C
Liquidus : 652 °C

6.3 WORK PIECE

The work piece was brought as a 1000 mm aluminium rod and was cut in our (KCT) lathe shop into 9 pieces each piece measuring 100 mm in length and 30 mm in diameter.

6.4 TOOLING

6.4.1 Cutting Tool

Due to high resistance and easy machinability for the hardened steel (AISI 52100), the tool material chosen for the study is Cubic Boron Nitride (CBN). The tool insert is Sandvik coromant TNGA 160404 S0 1030A 7015 with nose radius 0.4MM.PTFNR tool holder is used which provides 5^0 side cutting-edge angle, 5^0 end cutting –edge angle, -5^0 back rake angle.

6.4.2 Machine Tool Specification

A computer numerical control is used for conducting experiments. Specifications of the HMT ECONO 26 machine are shown in Table 5.2.

Table 6.2 Machine Tool Specification

Make	HMT
Model	ECONO 26
Distance between centers	1000
Feed Rate	1 – 7000 m/min
Spindle speed	0 – 2500 rpm
Rapid Feed Rate	5 m/min
Maximum Feed Rate	1 – 2000 mm/min
Tool Shank Size	25 X 25
Spindle Drive Motor	11 KW

6.5 EXPERIMENTAL SETUP

Experiments are conducted on HMT ECHONO CNC 26 LATHE IN PSG Industrial Institute, Coimbatore. For different sets of machining conditions experiments are conducted in order to obtain the surface roughness, cutting forces and temperatures. For measuring cutting forces nine set of experiments were conducted as per DOE (Design of Experiments). The work material is fixed to the chuck and the job is centered. The insert is clamped to the tool holder and the necessary settings are made. The process parameters selected for the experiments are speed, feed and depth of cut. The turning operations are carried out with the Tungsten carbide insert which are specified earlier. The entire experiments are carried out in dry condition without using any coolant.

6.6 EXPERIMENTAL DESIGN

According to the Taguchi's design an L9 orthogonal array is selected and nine combinations of experiments are performed for the selected levels of cutting parameters given.

Table 6.3 Factors and Levels tabulation

Symbol	Cutting parameters	Levels		
		1	2	3
A	Cutting speed (rpm)	1300	1400	1500
B	Feed(mm/min)	30	50	70
C	Depth of cut(mm)	.5	.75	1

6.7 SURFACE ROUGHNESS MEASUREMENT

6.7.1 Surface Finish

Surface Roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small the surface is smooth. Roughness is typically considered to be the high frequency; short wavelength component of a measured surface .Roughness plays an important role in determining how a real object will interact with its environment. Rough surfaces usually wear more quickly and have higher friction coefficients than smooth surfaces. Roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion.

Although roughness is usually undesirable, it is difficult and expensive to control in manufacturing. Decreasing the roughness of a surface will usually increase exponentially its manufacturing costs. This often results in a trade-off between the manufacturing cost of a component and its performance in application.

6.7.2 Surface Roughness Measurement

Roughness may be measured using contact or non-contact methods. Contact methods involve dragging a measurement stylus across the surface; these instruments include profilometers. Non-contact methods include interferometry, co focal microscopy, electrical capacitance and electron microscopy .For 2D measurements, the probe usually traces along a straight line on a flat surface or in a circular arc around a cylindrical surface. The length of surface profile that is scanned is usually called the measurement length. The wavelength of the lowest frequency filter that will be used to analyze the data is usually defined as the sampling length. Most standards recommend that the measurement length should be at least seven times longer than the sampling length, and according to the Nyquist–Shannon sampling theorem it should be at least ten times longer than the wavelength of interesting features. The assessment length or evaluation length is the length of data that will be used for analysis. Commonly one sampling length is discarded from each end of the measurement length.

For 3D measurements, the probe is commanded to scan over a 2D area on the surface. The spacing between data points may not be the same in both directions.

In some cases, the physics of the measuring instrument may have a large effect on the data. This is especially true when measuring very smooth surfaces. For contact measurements, most obvious problem is that the stylus may scratch the measured surface. Another problem is that the stylus may be too blunt to reach the bottom of deep valleys and it may round the tips of sharp peaks. In this case the probe is a physical filter that limits the accuracy of the instrument.

There are also limitations for non-contact instruments. For example instruments that rely on optical interference cannot resolve features that are less than some fraction of the frequency of their operating wavelength. This limitation can make it difficult to accurately measure roughness even on common objects, since the interesting features may be well below the wavelength of light. The wavelength of red light is about 650 nm, while the Ra of a ground shaft might be 2000 nm.

6.7.3 SurfTester

Mitutoyo SJ 201 Surftester is a surface roughness measuring device which is provided with exchangeable diamond stylus of radius of 5μ, which sensing the horizontal and vertical deflection from any surface gives roughness value. It has a graphic LCD display which directly gives a surface roughness value of measured surface. We have obtain the reading in terms of R_a

Fig 6.3 Surface Roughness testing

Technical Data

X-axis (drive unit)

Measuring range: .49" (12.5mm)

Measuring speed: .01", .02"/s (0.25, 0.5mm/s)

.01"/s (0.25mm/s: S-type)

Traversing direction: Backward

Detector

Range: 13780μin (-7880μin to+5900μin)

(350μm (-200μm to +150μm))

Detecting method: Skid measurement

Measuring force: 4mN or 0.75mN (low force type)

Stylus tip: Diamond, 90°/5μmR

(60°-/2μmR: low force type)

Skid radius of curvature: 40mm

Skid force: less than 400mN

Detecting method: Differential inductance

Power supply: Via AC adapter / rechargeable battery

Battery life: Max. 600 measurements (w/o printing)

Recharge time: 15 hours

The surface readings take during the study:

Table 6.4 Experimental readings

SPINDLE SPEED V (rpm)	FEED RATE f mm min^{-1}	DEPTH OF CUT (mm)	EXPERIMENTAL VALUES			AVERAGE VALUES (Ra)
			TRAIL 1	TRAIL 2	TRAIL 3	
1200	30	0.50	1.70	1.74	1.68	1.706
1200	30	0.75	2.26	2.42	2.18	2.286
1200	30	1.00	5.36	5.42	5.40	5.393
1200	50	0.50	2.72	2.78	2.66	2.720
1200	50	0.75	2.36	2.40	2.34	2.366
1200	50	1.00	4.48	4.42	4.46	4.460
1200	70	0.50	2.52	2.56	2.56	2.546
1200	70	0.75	1.62	1.58	1.72	1.640
1200	70	1.00	1.98	2.04	2.00	2.006
1300	30	0.50	3.56	3.66	3.62	3.613
1300	30	0.75	2.54	2.50	2.58	2.540
1300	30	1.00	5.78	5.74	5.80	5.773
1300	50	0.50	2.06	2.14	2.14	2.113
1300	50	0.75	2.04	2.12	2.08	2.080
1300	50	1.00	4.86	4.83	4.92	4.890
1300	70	0.50	1.70	1.78	1.78	1.753
1300	70	0.75	2.26	2.18	2.20	2.213
1300	70	1.00	2.32	2.28	2.40	2.333
1500	30	0.50	2.12	2.20	2.28	2.200
1500	30	0.75	2.98	3.00	3.26	3.080
1500	30	1.00	5.42	5.36	5.51	5.760
1500	50	0.50	3.32	3.26	3.66	3.413
1500	50	0.75	3.68	3.76	3.54	3.660
1500	50	1.00	4.96	4.98	4.93	4.956
1500	70	0.50	2.86	2.77	2.89	2.840
1500	70	0.75	2.68	2.76	2.74	2.726
1500	70	1.00	5.10	4.92	5.00	5.006

CHAPTER 7

OPTIMISATION USING DESIGN EXPERT

The optimization of the cutting parameters is done using the Taguchi technique which employs the L9 orthogonal array for our purpose. This optimization can be accomplished using the Design- Expert software which is one of the most widely used statistical software. The optimization can be finally developed using the interaction graph generated at the end of the process.

7.1 PROCEDURE

STEP 1: Open a new file in the Design- Expert software

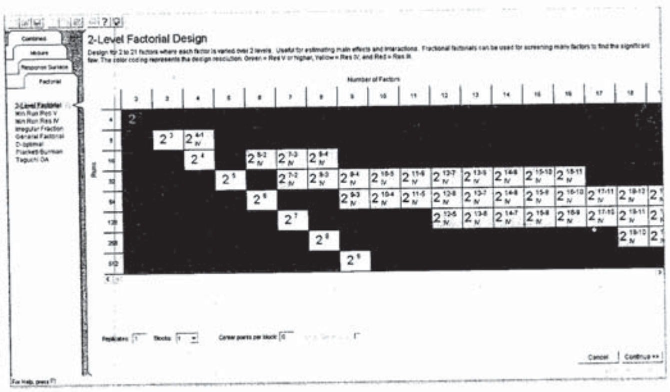


Fig 7.1 Design- Expert software procedure

STEP 2: Select Taguchi method for analyzing the data. After which we have to select L9 orthogonal array, since we have 3 levels and 3 factors to be considered.

Fig 7.2 Design- Expert software procedure

STEP 3: After select the L9 array, input the response which our case is " Surface roughness" , mention the unit for the response and the signal as 2 and noise factor as 0.5 and continue

Fig 7.3 Design- Expert software procedure

STEP 4: The L9 array can accommodate maximum of 4 factors, in our case we only have 3 so delete the factor 4 column from the standard L9 array.

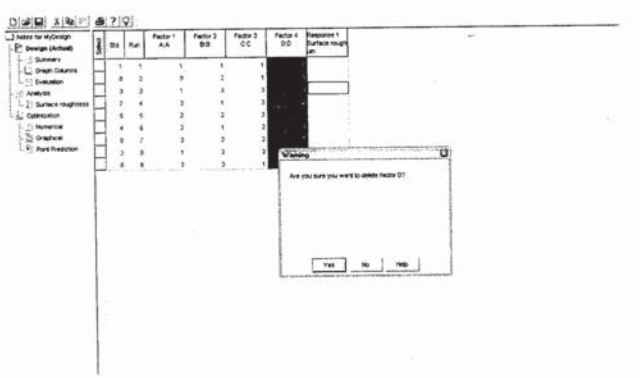
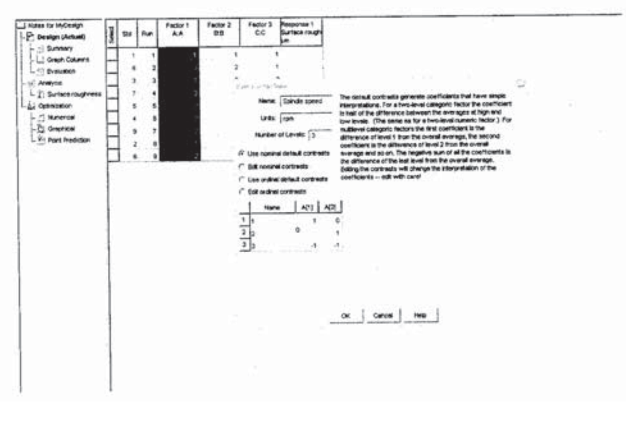


Fig 7.4 Design- Expert software procedure

STEP:5 Feed the factor details by right clicking the respective columns .The feeding the data mention the number of levels, the unit of the factor, this is to repeated for the other 2 factors as well.



STEP 6 : Arrange the array in standard order before input in the data into the columns

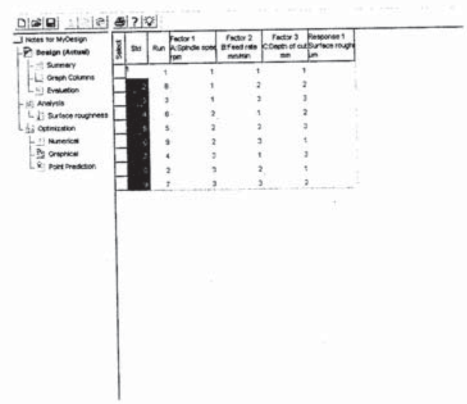


Fig 7.6 Design- Expert software procedure

STEP 7: Input the low and high values of the factors and clicking factor information.

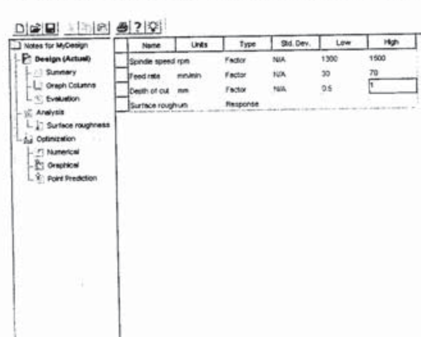


Fig 7.7 Design- Expert software procedure

STEP 8: The factor details for each run and the corresponding surface finish values are fed into the orthogonal array and then click evaluation .This will begin to analyses the data fed into the array.

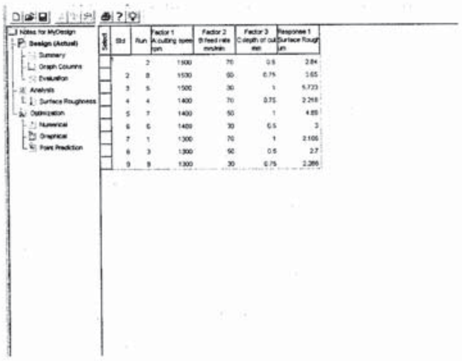


Fig 7.8 Design- Expert software procedure

STEP 9: The interaction between the factors must be specified to get the various graphical notations.

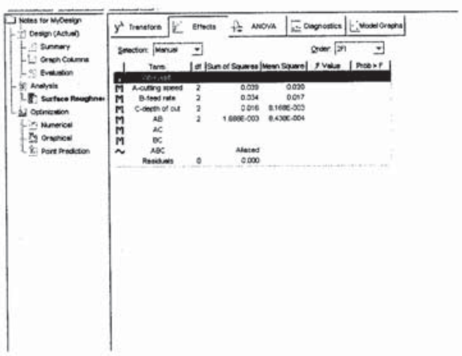


Fig 7.9 Design- Expert software procedure

STEP10: The various interaction graphs for various factors can be obtained, by selecting the "model" options .The different representation of the graphs can be got by selecting the appropriate options in the software.

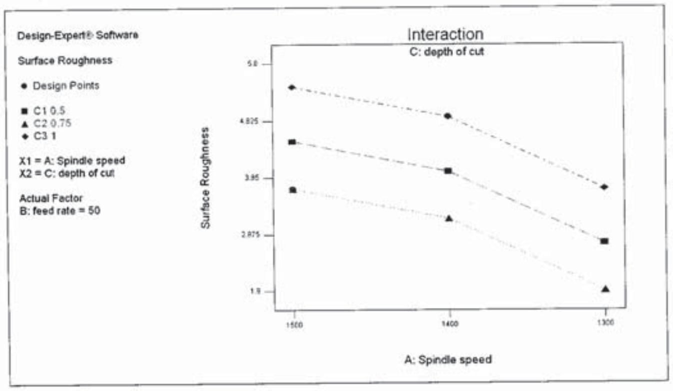


Fig 7.10 Design- Expert software procedure

CHAPTER 8

MATHEMATICAL MODEL USING QUALITY AMERICA

DOE –PC IV Version 3.01 (008) by Quality America is a tool that facilitates in the carrying out of design of experiments .To create the design , the factors that influence the process and their levels are entered . The feasible designs are displayed along with the most efficient one .

8.1 PROCEDURE

Step 1 : Open a new file in DOE-PC IV

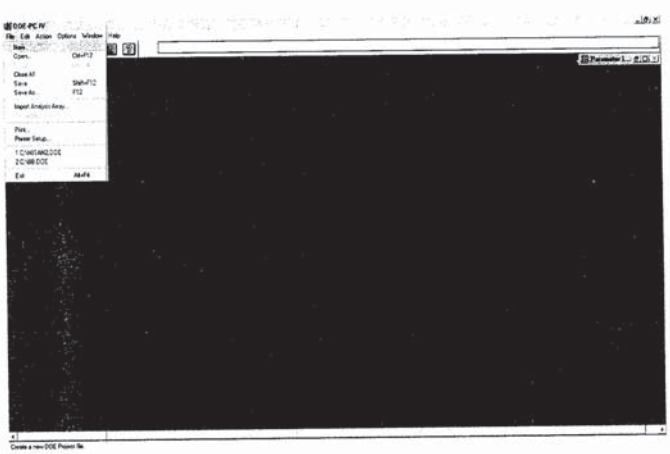


Fig 8.1 Quality America DOE software procedure

STEP 2 : To input the parameters choose the 'Add parameter' option in the Edit tab.

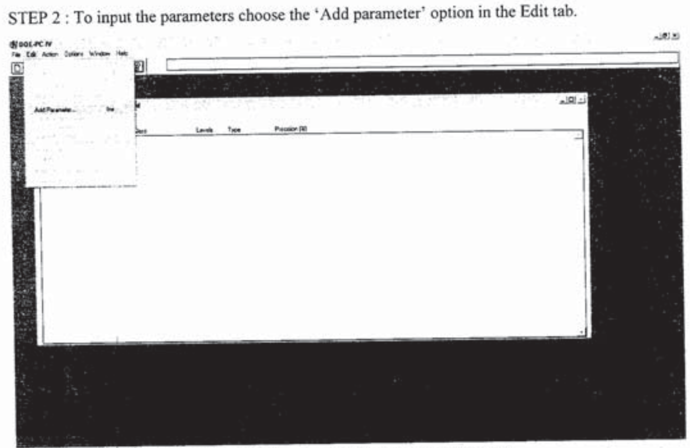
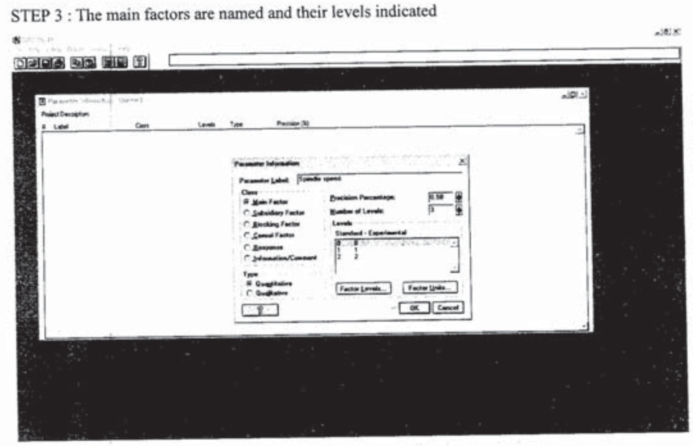


Fig 8.2 Quality America DOE software procedure

STEP 3 : The main factors are named and their levels indicated



STEP 4 : The limits and the units for the factors are then specified

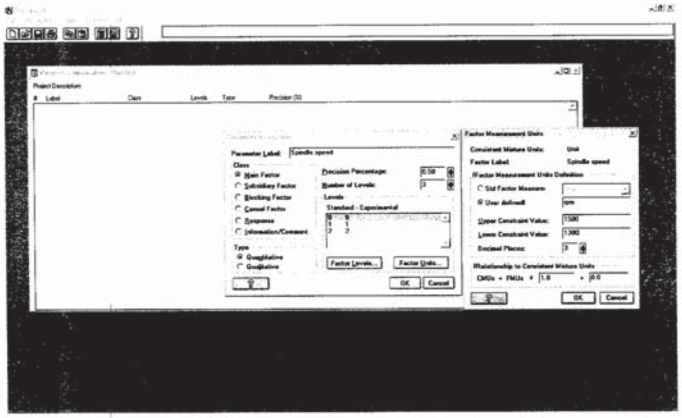
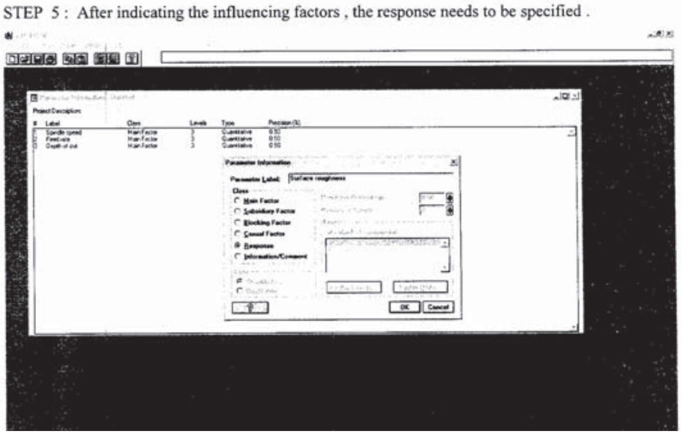


Fig 8.4 Quality America DOE software procedure

STEP 5 : After indicating the influencing factors , the response needs to be specified .



STEP 6 :To create the Main Factor Interaction Array click on the option in the Action tab

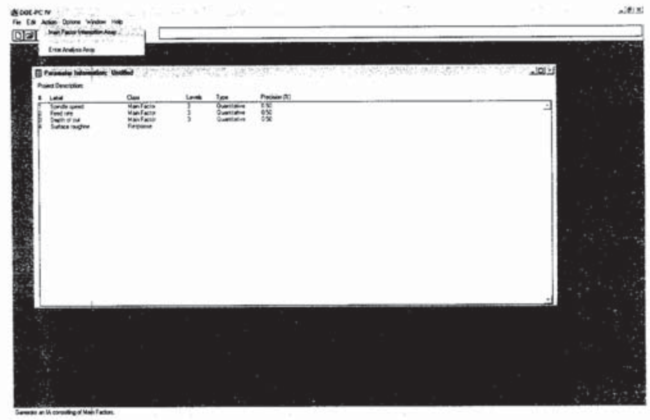
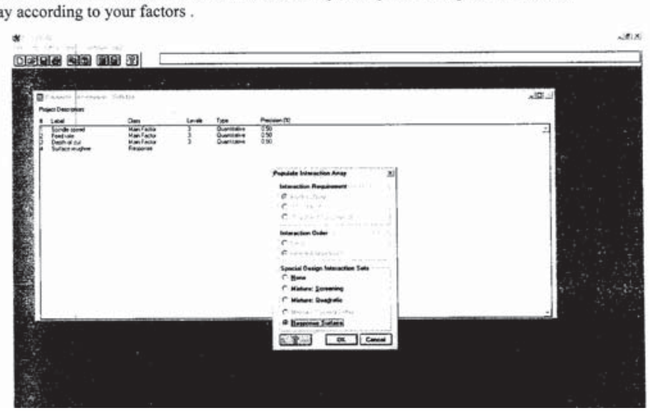


Fig 8.6 Quality America DOE software procedure

STEP 7 : To obtain the Main Factor Interaction Array , complete the Populate Interaction Array according to your factors .



STEP 8 : The Main Factor Interaction Array is created . To create the Design array , select the option in the Action tab .

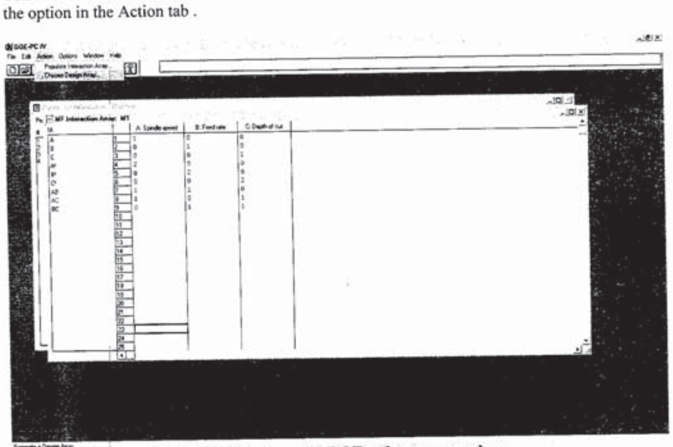
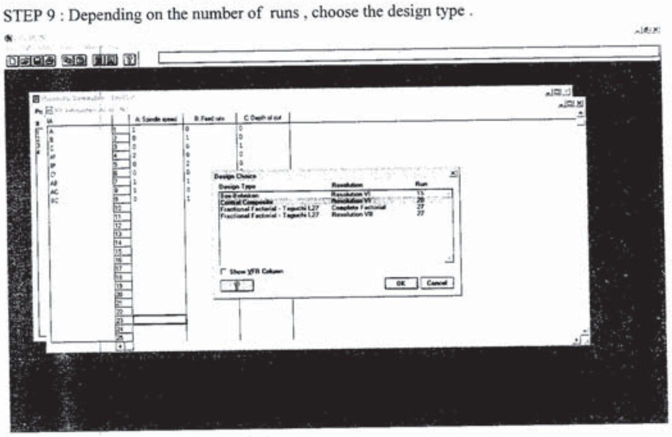


Fig 8.8 Quality America DOE software procedure

STEP 9 : Depending on the number of runs , choose the design type .



STEP 10 : To create the Final Design Array , choose the option in the action tab .

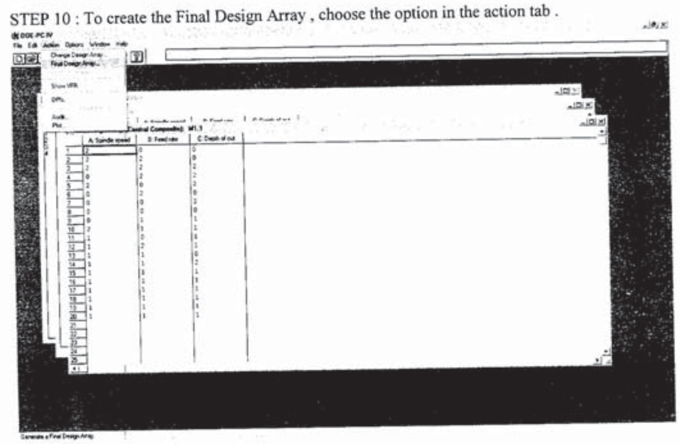
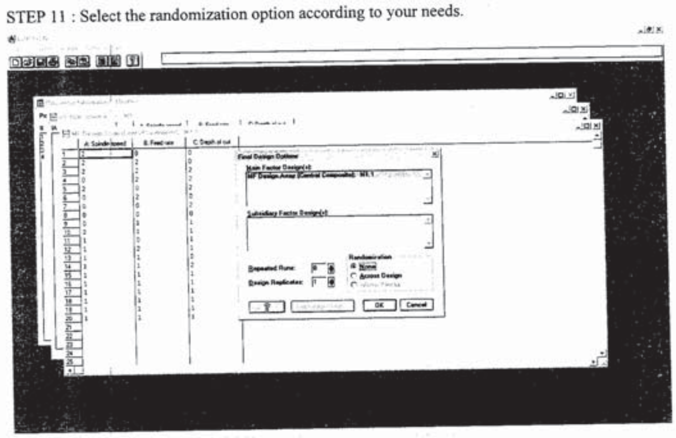


Fig 8.10 Quality America DOE software procedure

STEP 11 : Select the randomization option according to your needs.



STEP 12 : Now to build the analysis array , choose the option in the Action array .

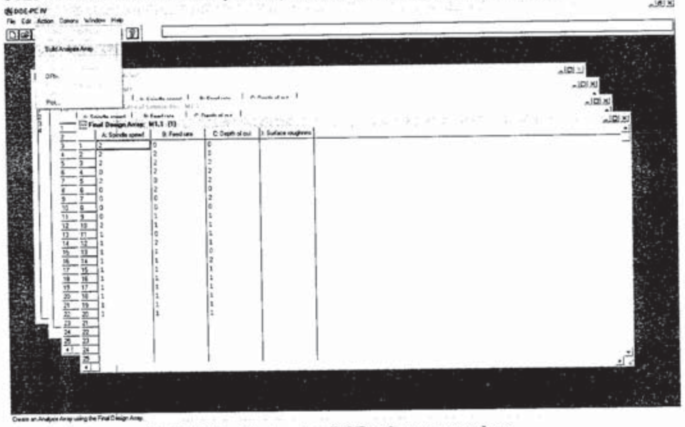
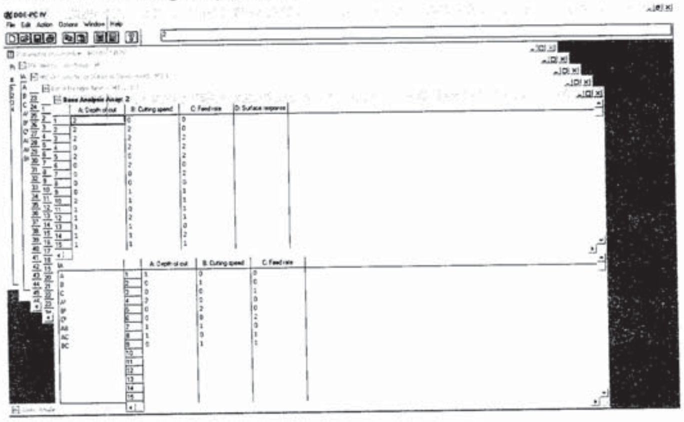


Fig 8.12 Quality America DOE software procedure

STEP 13 : The final design array is created .



STEP 14: The respective values for the factors are entered in to the columns .

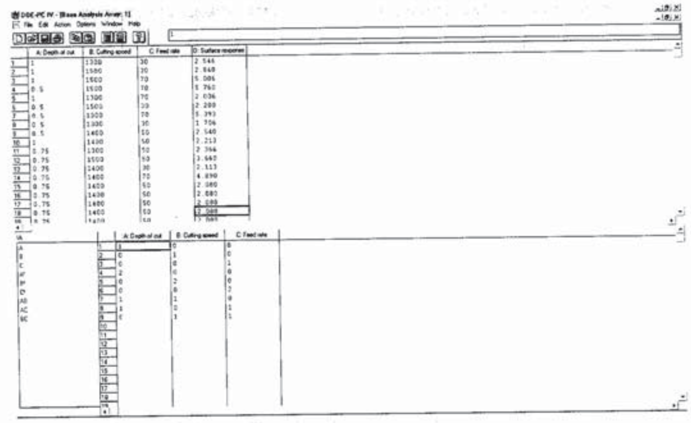
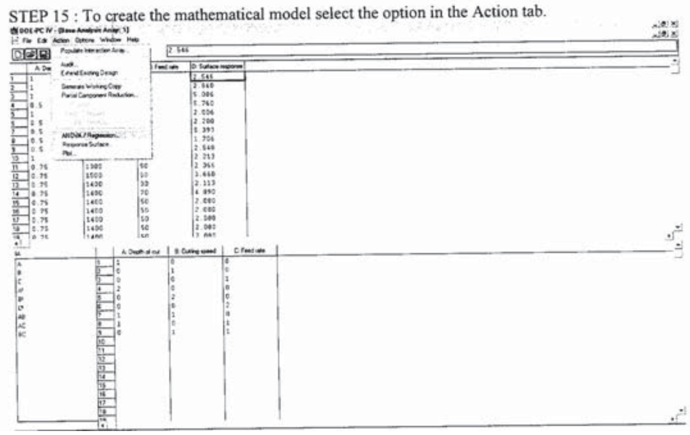
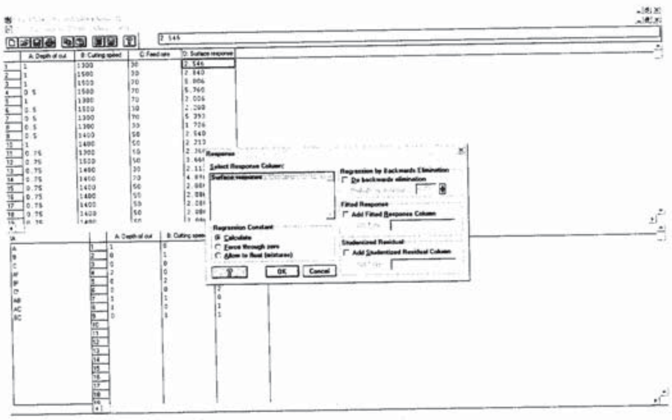


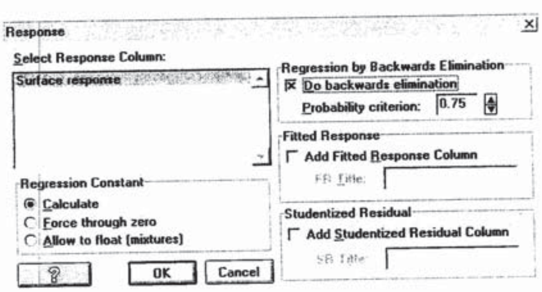
Fig 8.15 Quality America DOE software procedure

STEP 15 : To create the mathematical model select the option in the Action tab.

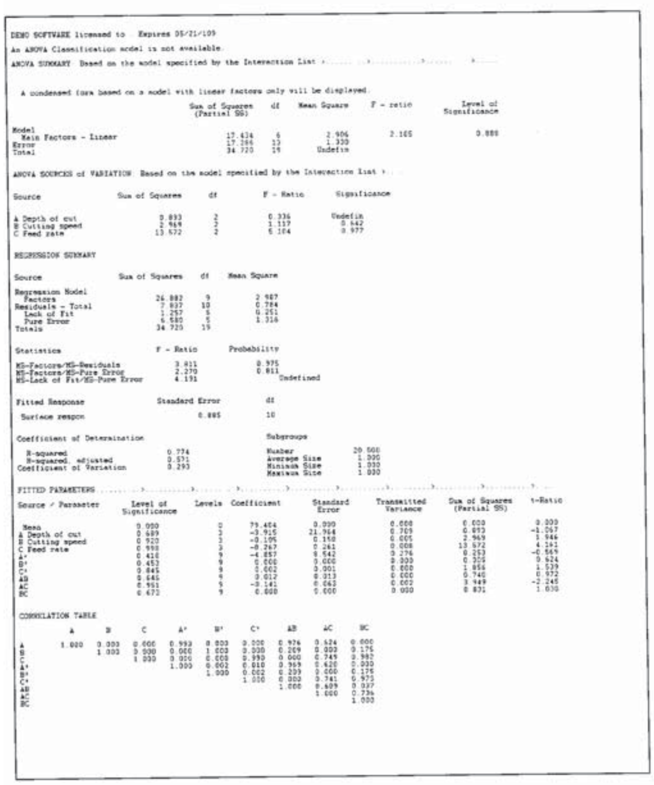


STEP 16 : The mathematical model can be generated through 2 methods . On selecting the backward elimination method the mathematical model will be better optimized with lesser number of variable .





STEP 17 : The mathematical model is thus created



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An ANOVA Classification model is not available.

ANOVA SUMMARY Based on the model specified by the Interaction List

A condensed form based on a model with linear factors only will be displayed.

	Sum of Squares (Partial SS)	df	Mean Square	F - ratio	Level of Significance
Model					
Main Factors - Linear	17.434	6	2.906	2.185	0.888
Error	17.286	13	1.330		
Total	34.720	19	Undefin		

ANOVA SOURCES of VARIATION Based on the model specified by the Interaction List

Source	Sum of Squares	df	F - Ratio	Significance
A Depth of cut	0.893	2	0.336	Undefin
B Cutting speed	2.969	2	1.117	0.642
C Feed rate	13.572	2	5.104	0.977

REGRESSION SUMMARY

Source	Sum of Squares	df	Mean Square
Regression Model			
Factors	26.882	9	2.987
Residuals - Total	7.837	10	0.784
Lack of Fit	1.257	5	0.251
Pure Error	6.580	5	1.316
Totals	34.720	19	

Statistics	F - Ratio	Probability
MS-Factors/MS-Residuals	3.811	0.975
MS-Factors/MS-Pure Error	2.270	0.811
MS-Lack of Fit/MS-Pure Error	4.191	Undefined

Fitted Response	Standard Error	df
Surface respon	0.885	10

Coefficient of Determination		Subgroups	
R-squared	0.774	Number	20.000
R-squared, adjusted	0.571	Average Size	1.000
Coefficient of Variation	0.293	Minimum Size	1.000
		Maximum Size	1.000

FITTED PARAMETERS

Source / Parameter	Level of Significance	Levels	Coefficient	Standard Error	Transmitted Variance	Sum of Squares (Partial SS)	t-Ratio
Mean	0.000	0	79.404	0.000	0.000	0.000	0.000
A Depth of cut	0.689	3	-3.915	21.964	0.709	0.893	-1.067
B Cutting speed	0.920	3	-0.105	0.150	0.005	2.969	1.946
C Feed rate	0.998	3	-0.267	0.261	0.008	13.572	4.161
A'	0.418	9	-4.857	8.542	0.276	0.253	-0.569
B'	0.453	9	0.000	0.000	0.000	0.309	0.624
C'	0.845	9	0.002	0.001	0.000	1.856	1.539
AB	0.645	9	0.012	0.013	0.000	0.740	0.972
AC	0.951	9	-0.141	0.063	0.002	3.949	-2.245
BC	0.672	9	0.000	0.000	0.000	0.831	1.030

CORRELATION TABLE

	A	B	C	A'	B'	C'	AB	AC	BC
A	1.000	0.003	0.000	0.993	0.003	0.000	0.976	0.624	0.000
B		1.003	0.000	0.000	1.003	0.000	0.209	0.003	0.175
C			1.000	0.000	0.000	0.990	0.000	0.749	0.982
A'				1.000	0.002	0.010	0.969	0.620	0.030
B'					1.000	0.002	0.209	0.000	0.175
C'						1.000	0.002	0.741	0.973
AB							1.000	0.609	0.037
AC								1.000	0.736
BC									1.000

```
DEMO SOFTWARE licensed to   Expires 05/21/105
An ANOVA Classification model is not available.
ANOVA SUMMARY  Based on the model specified by the Interaction List >....

 A condensed form based on a model with linear factors only will be displayed
                                   Sum of Squares   df   Mean Square    F - ratio     Level of
                                   (Partial SS)                                       Significance
Model
  Main Factors - Linear                17.434        6       2.906        2.185          0.889
Error                                  17.286       13       1.330
Total                                  34.720       19      Undefin

ANOVA SOURCES of VARIATION: Based on the model specified by the Interaction List >....

Source                Sum of Squares     df        F - Ratio      Significance

A Depth of cut             0.893          2          0.336          Undefin
B Cutting speed            2.969          2          1.117           0.642
C Feed rate               13.572          2          5.104           0.977

REGRESSION SUMMARY

****ANALYSIS DONE USING BACKWARDS ELIMINATION******
****t-Probability criterion was  0.75

Source                Sum of Squares    df    Mean Square

Regression Model
  Factors                 22.493         4       5.623
Residuals - Total         12.227        15       0.815
  Lack of Fit              5.647        10       0.565
  Pure Error               6.580         5       1.316
Totals                    34.720        19

Statistics                    F - Ratio       Probability

MS-Factors/MS-Residuals         6.898            0.998
MS-Factors/MS-Pure Error        4.273            0.920
MS-Lack of Fit/MS-Pure Error    5.425                 Undefined

Fitted Response              Standard Error          df

 Surface respon                      0.903            1

Coefficient of Determination                   Subgroups

  R-squared                    0.648           Number            20.000
  R-squared, adjusted          0.554           Average Size       1.000
Coefficient of Variation       Undefined       Minimum Size       1.000
                                               Maximum Size       1.000

FITTED PARAMETERS..........>..........>..........>..........>..........>..........>

Source / Parameter    Level of      Levels  Coefficient   Standard   Transmitted   Sum of Squares   t-Ratio
                      Significance                        Error      Variance      (Partial SS)

 Mean                   0.000          0      -2.690       0.000       0.000          0.000          0.000
B Cutting speed         0.924          3       0.005       0.003       0.022          2.969          1.909
C Feed rate             0.999          3      -0.124       0.103       0.803         13.572          4.080
C²                      0.945          9       0.002       0.001       0.008          3.520          2.070
AC                      0.956          9      -0.037       0.022       0.167          3.949         -2.201

CORRELATION TABLE

            B        C       C²       AC

B         1.000    0.000    0.000    0.000
C                  1.000    0.990    0.749
C²                          1.000    0.741
AC                                   1.000
```

Fig 8.17 Final output of DOE

CHAPTER 9

ANALYSIS AND RESULT DISCUSSION

The optimization to find the ideal machining conditions was one using the Design – Expert software. The ideal condition must be found using the interaction graph rather then using the individual graphs. We get a total of 9 interaction graphs for 3 interactions at 3 different levels.

9.1 INTERACTION BETWEEN FEED RATE AND SPINDLE SPEED

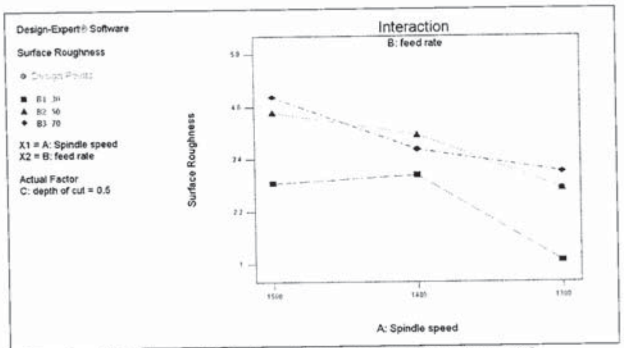
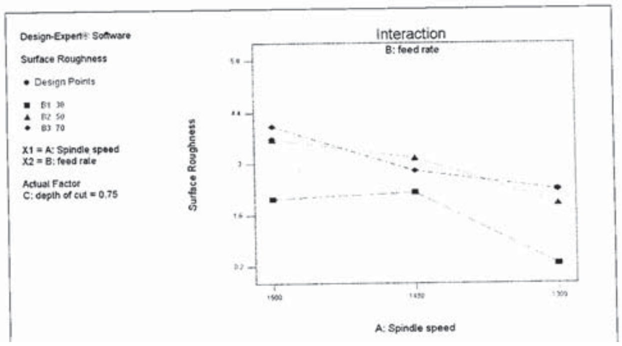


Fig 9.1 Interaction between feed rate and speed at DOC = 0.5



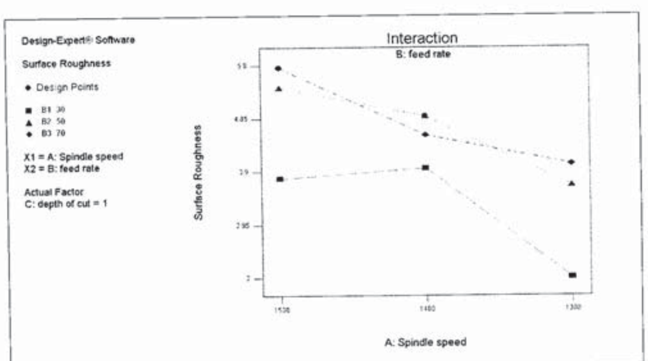


Fig 9.3 Interaction between feed rate and speed at DOC = 1

9.2 INFERENCE:

It evident the surface finish decreases with decrease in spindle speed.
It is also evident that the surface decreases with decrease in feed rate.

9.3INTERACTION BETWEEN DEPTH OF CUT AND SPINDLE SPEED

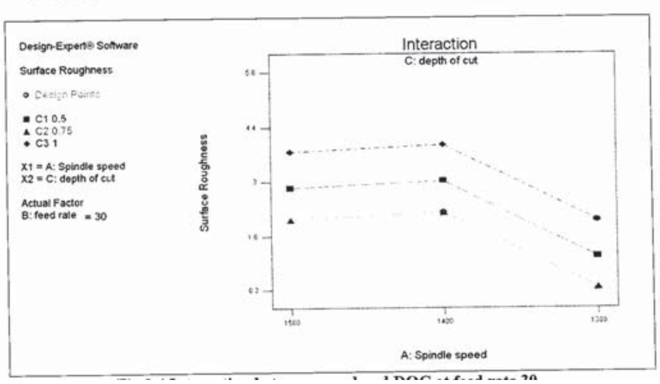


Fig 9.4 Interaction between speed and DOC at feed rate 30

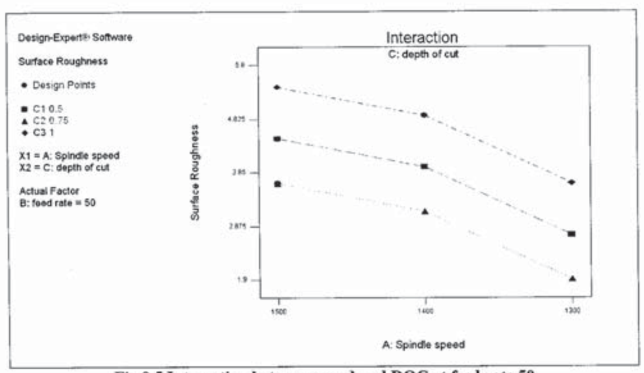


Fig 9.5 Interaction between speed and DOC at feed rate 50

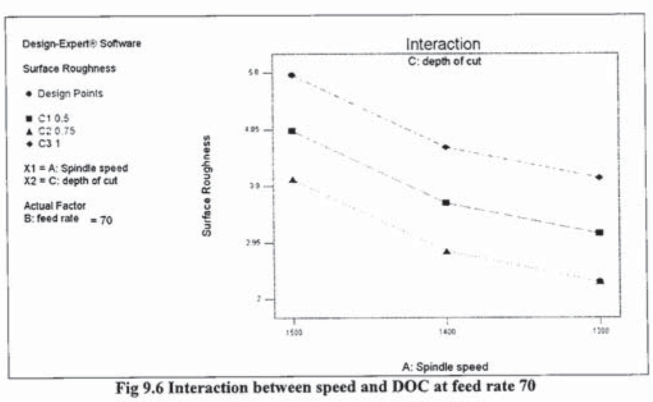


Fig 9.6 Interaction between speed and DOC at feed rate 70

9.4 INFERENCE

It is evident that the surface roughness decreases with decrease in spindle speed.
It is also evident that the surface roughness lowest at 0.75 level with maximum value reached at DOC = 1

9.5 INTERACTION BETWEEN DEPTH OF CUT AND FEED RATE

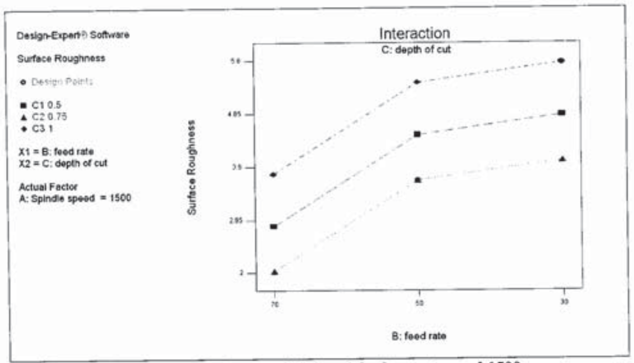


Fig 9.7 Interaction between DOC and feed rate at speed 1500 rpm

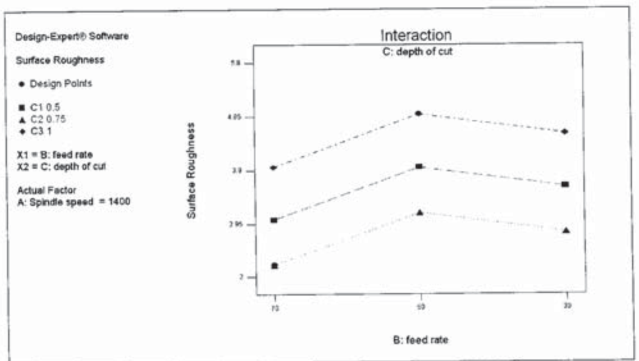


Fig 9.8 Interaction between DOC and feed rate at speed 1400 rpm

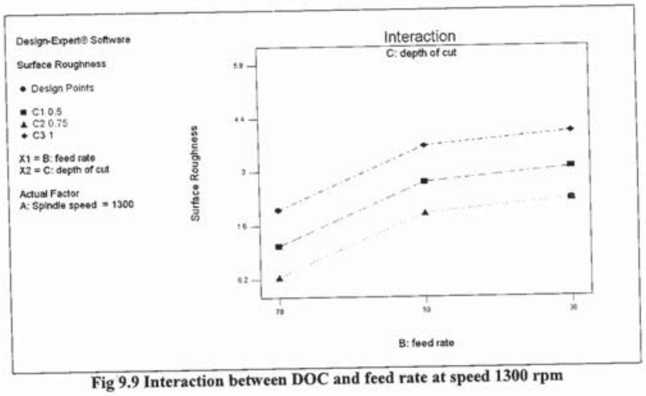


Fig 9.9 Interaction between DOC and feed rate at speed 1300 rpm

9.6 INFERENCE

It is evident that the surface roughness decreases with decrease in feed rate.
It is also evident that the surface roughness lowest at 0.75 level with maximum value reached at DOC = 1

9.7 OPTIMIZATION OF THE PARAMETERS

The lowest surface roughness values from the above 9 graphs is taken and tabulated with the occurring conditions in all cases and it is clearly seen the lowest surface roughness occurs at the following conditions:

Spindle speed : 1300 rpm
Depth of cut : 0.75 mm
Feed rate : 30 mm/min.

The tabulation is shown in the following page.

Table 9.1 Optimization table

S.No	Interaction	Surface Roughness (um)	Specified level of the varying factor	Occurring Conditions
1	Feed rate & Depth of cut	0.2	1300	(30 , 0.75)
		2.2	1400	(30, 0.75)
		2	1500	(30, 0.75)
2	Feed rate & Spindle speed	1.1	0.5	(30,1300)
		0.2	0.75	(30,1300)
		2	1	(30,1300)
3	Depth of cut & Spindle speed	0.2	30	(0.75,1300)
		1.9	50	(0.75,1300)
		2.5	70	(0.75,1300)

9.8 CONFIRMATORY TEST FOR SURFACE ROUGHNESS

Table 9.2 Confirmatory test readings

Trail no	Spindle speed (m/min)	Feed rate (mm/min)	DOC (mm)	Surface Roughness in Ra (µm)
1	1300	30	.75	1.213
2	1300	30	.75	1.209
3	1300	30	.75	1.204

It is evident from the above Table 9.2 that the surface roughness values resulted by setting the optimized value of process parameters lie between the estimated limits.

9.9 ANALYSIS OF VARIANCE

The analysis of variance ANOVA was done using the MINITAB software.
The percentage contribution of each factor for surface roughness can be calculated by the ANOVA technique .A three-Way ANOVA is performed for the average surface roughness values and the contribution for each cutting parameter can be seen in the table 9.1

Table 9.3 ANOVA table

Source	SS	DOF	F_{CAL}	F_{TAB}	P
Speed	5.6595	2	8.69	19	0.103
Feed	3.3727	2	5.18	19	0.162
DOC	6.5907	2	10.11	19	0.090
Error	0.6516	2			
Total	16.2745	8			

SS-sum of squres ; DOF- degrees of freedom; F_{TAB} – F Table value ; Fcal- Variance ratio ; P-Percentage of combinatiion

It is clear that the feed rate has a lot of effect on the surface roughness.

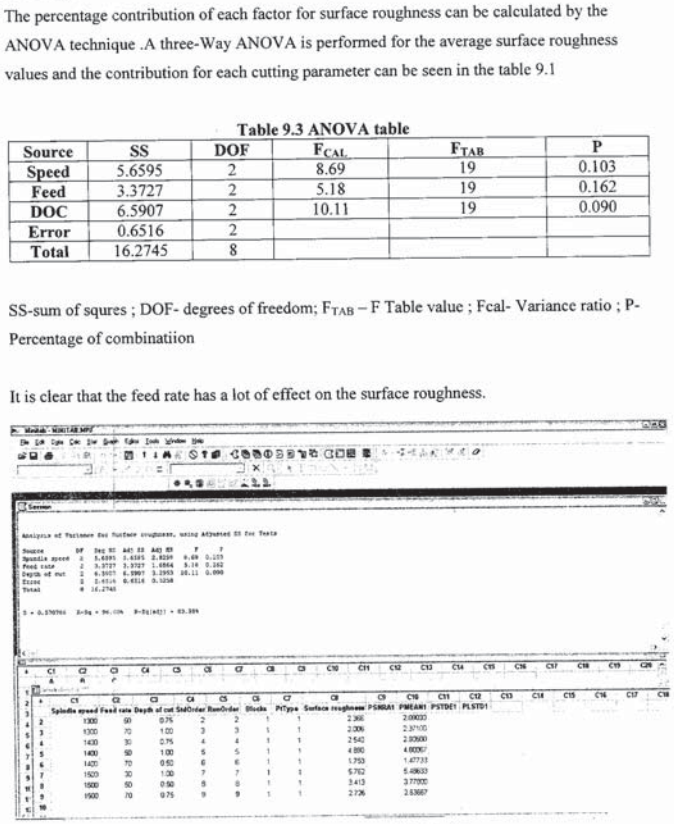


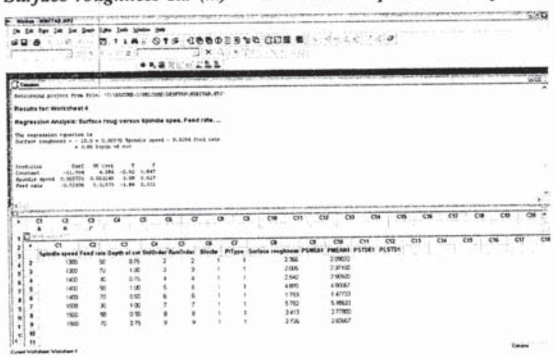
Fig 9.9ANOVA table using MINITAB software

9.10 REGRESSION MODEL

Regression analysis is a part of statistics that deals with the investigation of the relationship between two or more variables. Simple linear regression examines the linear relationship between two continuous variables: one response (y) and one predictor (x).When the two variables are related, it is possible to predict a response value from a predictor value with better than chance accuracy. Regression provides the line that 'best' fits the data. This line can then be used for two reasons one is to examine how the response variable changes as the predictor variable changes and the second is to predict the value of a response variable (y) for any predictor variable (x). In statistics, regression analysis examines the relation of a dependent variable (response variable) to specified independent variables (predictors). The mathematical model of their relationship is called as regression equation. The dependent variable is modeled as a random variable because of uncertainty as to its value, given values of the independent variables. Regression analysis estimates relationships between one or more response variables (also called dependent variables, explanatory variables, and control variables).

Multiple linear regression analysis is done using MINITAB software which predicts surface roughness as a function of the input cutting speed, feed and depth of cut. Multiple linear regression analysis is done using MINITAB software which predicts surface roughness as a function of the input cutting speed, feed and depth of cut. The regression equation is

Surface roughness Ra (m) = -12+ 0.00970 speed -0.0292 feed + 3.86 DOC



9.11 MATHEMATICAL MODEL:

The mathematical model was developed using Quality America Software using the Design of Experiment as factorial method with 20 runs so as to develop a more comprehensive model.

9.11.1 Complete mathematical model

Surface roughness = 79.404 = (- 3.915) A + (- 0.105) B + (- 0.267) C + (- 4.857) A^2 + (0.000) B^2 + (0.002)C^2 + (0.012) AB + (- 0.141) AC + (0.00) BC

9.11.2 Mathematical model through backward elimination model

Surface roughness = -2.690 + (0.005) B + (- 0.124) C + (0.002) C^2 + (-0.037) AC

9.12 ADEQUACY TEST:

S.No	Criteria	Model value	F-Table vale	Validity
1	$F_{model} < F_{table}$	4.273	5.1922	valid
2	$R_{model} > R_{table}$	5.429	4.7351	valid

Table 9.3 Adequacy test

CHAPTER 10

CONCLUSION

- Surface roughness is optimized using Taguchi technique and the optimum cutting levels found from this experimental study are,
- Cutting speed = 1300 rpm
- Feed rate = 30mm/min
- Depth of cut = 0.75 mm
- Using ANOVA technique the parameters that most affect the surface roughness is found to be feed rate
- The regression equation was formed using Taguchi technique.
- It is found that the required surface finish could be obtained in a single run using hard turning and complete remove the post turning operation of grinding. Thus saving considerable amount of cost.

10.1 SCOPE FOR FUTURE WORK

To continue this project work, the following suggestions are made for the improvement of the project.

- The effect of cutting parameters and tool geometry on surface roughness, cutting forces and tool wear can be investigated for different CBN cutting grades and hardness of work material.
- Multi-objective optimization can be done for reducing tool wear and maximizing surface finish.
- Effect of tool wear on surface roughness, cutting forces can be studied for various values of cutting parameters.
- Thickness of while layer can be calculated for different cutting conditions.
- A model can be developed to calculate the residual stress at various depths of cut
- The same analysis be also be done by considering the full factorial method with more parameters.

CHAPTER 11

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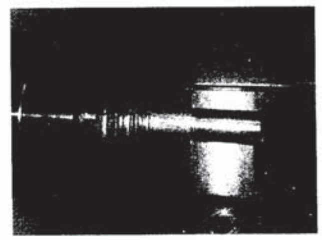
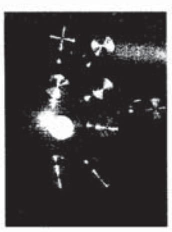
- R.S. Pawadea, Suhas S. Joshia, P.K. Brahmankar," Effect of machining parameters and cutting edge geometry on surface integrity of high-speed turned Inconel 718", International Journal of Machine Tools & Manufacture, 2008.

APPENDIX

Specimen rod being cut into smaller lengths



Metal being machined in the CNC turning center



Machined rods

Surface roughness of the machined area being measured