A CASE STUDY TO SOLVE MULTI-RESPONSE OPTIMIZATION PROBLEM

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In

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By

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Certificate

*This is to certify that the thesis entitled "**A CASE STUDY TO SOLVE MULTI-RESPONSE OPTIMIZATION PROBLEM**" submitted by Sri ANSHUMAN DASH has been carried out under my supervision in partial fulfillment of the requirements for the Degree of Bachelor of Technology in Mechanical Engineering at National Institute of Technology, Rourkela and this work has not been submitted elsewhere before for any other academic degree/diploma.*

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ABSTRACT

In machining operations, achieving desired surface quality features of the machined product, is really a challenging job. Because, these quality features are highly correlated and are expected to be influenced directly or indirectly by the direct effect of process parameters or their interactive effects (i.e. on process environment). However, the extents of significant influence of the process parameters are different for different responses. Therefore, optimization of surface roughness is a multi-factor, multi-objective optimization problem. Therefore, to solve such a multi-objective optimization problem, it is felt necessary to identify the optimal parametric combination, following which all objectives could be optimized simultaneously. In this context, it is essential to convert all the objective functions into an equivalent single objective function or overall representative function to meet desired multi-quality features of the machined surface. The required multi-quality features may or may not be conflicting in nature. The representative single objective function, thus calculated, would be optimized finally. In the present work, Design of Experiment (DOE) with Taguchi L_9 Orthogonal Array (OA) has been explored to produce 9 specimens on copper bard by straight turning operation. Collected data related to surface roughness have been utilized for optimization. Principal Component Analysis (PCA) has been applied to eliminate correlation among the responses and to evaluate independent or uncorrelated quality indices called principal components. Based on quality loss of individual principal components with respect to the ideal condition, CQL (COMBINED QUALITY LOSS) has been calculated to serve as the single objective function for optimization. Finally, Taguchi method has been adopted for searching optimal process condition to yield desired surface quality. Result of the aforesaid optimization procedure has been verified through confirmatory test. The study illustrates the detailed methodology of PCA based Taguchi method and its effectiveness for multi-response surface quality optimization in turning operation.

CHAPTER 1

- ***Introduction***
- ***Literature Review***

INTRODUCTION

1.1 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.

Figure 1: Turning Operation

1.2 CHUCKING THE WORK PIECE

The work piece can be safely turned in the three jaw chuck without supporting the free end of the work. For longer work pieces we would need to face and center drill the free end and use a dead or live center in the tailstock to support the work piece. Without such support, the force of the tool on the work piece would cause it to bend away from the tool, producing a strangely shaped result.

Figure 2: Work Piece Mounted On Chuck

1.3 ***CUTTING TOOLS***

Cutting tool is device with which a material could be cut to the desired size, shape or finish. So a cutting tool must have at least a sharp edge. There are two types of cutting tool. The tool having only one cutting edge is called *Single Point Cutting Tools*. For example shaper tools, lathe tools, planer tools, etc. The tool having more than one cutting edge is called *Multipoint Cutting Tools*. For example drills, milling cutters, broaches, grinding wheel honing tool etc.

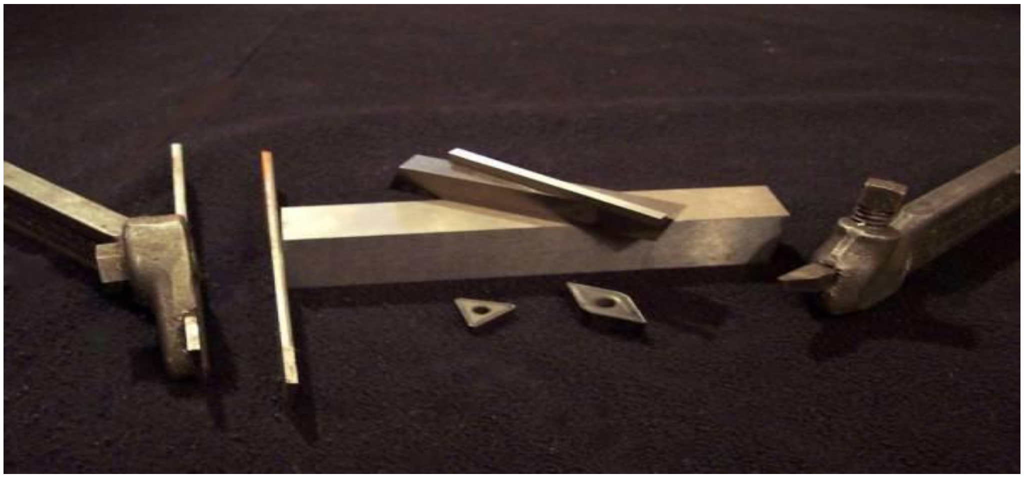

Figure 2: Various Tool Bits, Carbide Inserts and Tool Holders

*1.3.1 **TOOL GEOMETRY***

The geometry of a cutting tool consists of the following elements: face or rake surface, flank, cutting edges and the corner.

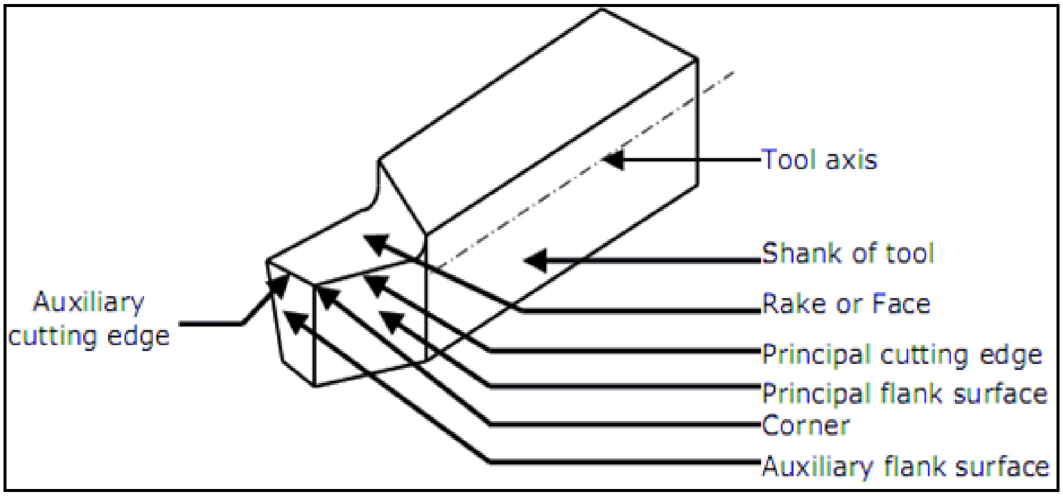

Figure 3: Elements of a Single Point Turning Tool

For cutting tools, geometry depends mainly on the properties of the tool material and the work material. A single point cutting tool may be either right or left hand cut tool depending on the direction of feed.

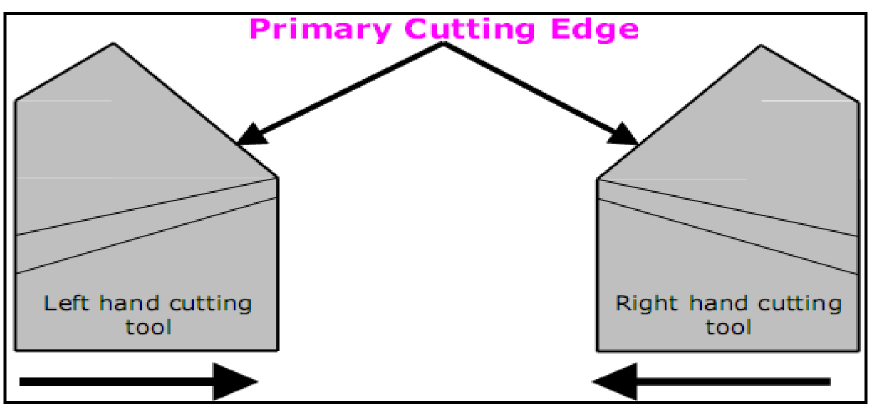

Figure 4: Left Hand and Right Hand Cutting Tool

The standard terminology is shown in the following figure. For single point tools, the most important angles are the rake angles and the end and side relief angles.

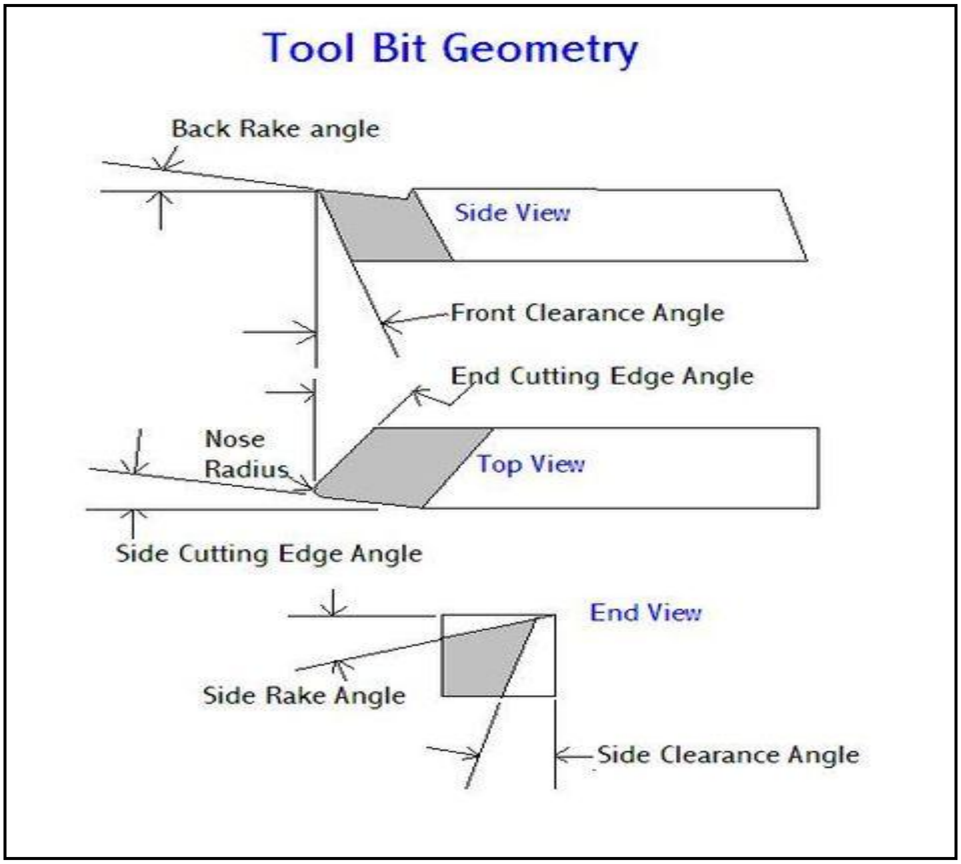

Figure 5: Tool Bead Geometry

1.3.2 METHODS OF MACHINING

In the metal cutting operation, the tool is wedge-shaped and has a straight cutting edge. Basically, there are two methods of metal cutting, depending upon the arrangement of the cutting edge with respect to the direction of relative work-tool motion:

(1) Orthogonal Cutting or Two Dimensional Cutting

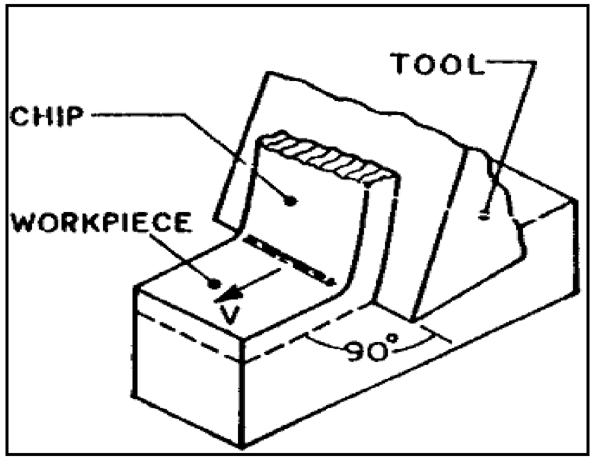

Figure 6: Orthogonal Cutting or Two Dimensional Cutting

- The cutting edge of the tool remains at 90^0 to the direction of feed (of the tool or the work)
- The chip flows in a direction normal to the cutting edge of the tool
- The cutting edge of the tool has zero inclination with the normal to the feed.

(2) Oblique Cutting or Three Dimensioning Cutting

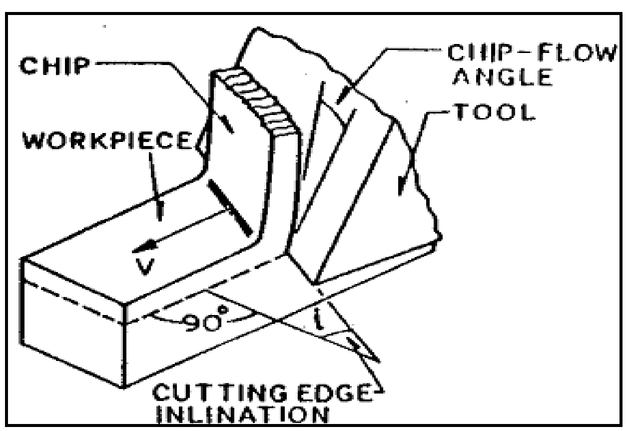

Figure 7: Oblique Cutting or Three Dimensioning Cutting

- The cutting edge of the tool remains inclined at an acute angle to the direction of feed (of the work or tool)
- The direction of the chip flow is not normal to the cutting edge. Rather it is at an angle β to the normal to the cutting edge.
- The cutting edge is inclined at an angle λ to the normal to the feed. This angle is called inclination angle.

*1.3.3 **CUTTING TOOL MATERIALS***

Selecting the appropriate cutting tool material for a specific application is crucial in achieving efficient operations. Increasing cutting speed to increase productivity is only possible to a limited extent as this shortens the tool life, increasing tool re-grinding/ replacement costs and increasing interruptions to production.

No single material meets all requirements. The properties needed by cutting tools mean compromise is needed, for example increasing hardness generally results in lower toughness.

The Ideal cutting tool material should have all of the following characteristics:

- Harder than the work it is cutting
- High temperature stability
- Resists wear and thermal shock
- Impact resistant
- Chemically inert to the work material and cutting fluid

To effectively select tools for machining, a machinist or engineer must have specific information about:

- The starting and finished part shape
- The work piece hardness
- The material's tensile strength
- The material's abrasiveness
- The type of chip generated
- The work holding setup
- The power and speed capacity of the machine tool

High Carbon Steel

Contains 1 - 1.4% carbon with some addition of chromium and tungsten to improve wear resistance. The steel begins to lose its hardness at about 250° C, and is not favored for modern machining operations where high speeds and heavy cuts are usually employed.

High Speed Steel (HSS)

Steel, which has a hot hardness value of about 600° C, possesses good strength and shock resistant properties. It is commonly used for single point lathe cutting tools and multi point cutting tools such as drills, reamers and milling cutters.

Cemented Carbides

An extremely hard material made from tungsten powder. Carbide tools are usually used in the form of brazed or clamped tips. High cutting speeds may be used and materials difficult to cut with HSS may be readily machined using carbide tipped tool.

1.3.4 DESIGNATION OF CUTTING TOOLS

Designation or nomenclature of a cutting tool is meant the designation of the shape of the cutting part of the tool. The following systems to designate the cutting tool shape which are widely used are:

- Tool in Hand System
- Machine Reference System or American Standard Association (ASA) System
- Tool Reference System
- Orthogonal Rake System (ORS)
- Normal Rake System (NRS)
- Maximum Rake System (MRS)
- Work Reference System (WRS)

1.4 ADJUSTABLE CUTTING FACTORS IN TURNING

The three primary factors in any basic turning operation are speed, feed, and depth of cut. Other factors such as kind of material and type of tool have a large influence, of course, but these three are the ones the operator can change by adjusting the controls, right at the machine.

Speed

Speed always refers to the spindle and the work piece. When it is stated in revolutions per minute (rpm) it tells their rotating speed. But the important feature for a particular turning operation is the surface speed, the speed at which the work piece material is moving past the cutting tool. It is simply the product of the rotating speed times the circumference of the work piece before the cut is started. It is expressed in meter per minute (m/min), and it refers only to the work piece. Every different diameter on a work piece will have a different cutting speed, even though the rotating speed remains the same.

$$v = \frac{\pi DN}{1000} m\ min^{-1}$$

Here, v is the cutting speed in turning,

D is the initial diameter of the work piece in mm and N is the spindle speed in RPM.

Feed

It is the rate at which the tool advances along its cutting path. The feed of the tool also affects to the processing speed and the roughness of surface. When the feed is high, the processing speed becomes quick. When the feed is low, the surface is finished beautiful. There are 'manual feed' which turns and operates a handle, and 'automatic feed' which advances a byte automatically. A beginner must use the manual sending. Because serious accidents may be caused, such as touching the rotating chuck around the byte in automatic feed.

On most power-fed lathes, the feed rate is directly related to the spindle speed and is expressed in mm (of tool advance) per revolution (of the spindle), or mm/rev.

F_m= f. N mm. min^{-1}

Here, F_m is the feed in mm per minute, f is the feed in mm/rev and N is the spindle speed in RPM.

Depth of Cut

Depth of cut is practically self explanatory. It can be defined as the thickness of the layer being removed (in a single pass) from the work piece or the distance from the uncut surface of the work to the cut surface, expressed in mm.

$$d_{cut} = \frac{D - d}{2}\ mm$$

Here, D and d represent initial and final diameter (in mm) of the job respectively.

It is important to note, though, that the diameter of the work piece is reduced by two times the depth of cut because this layer is being removed from both sides of the work.

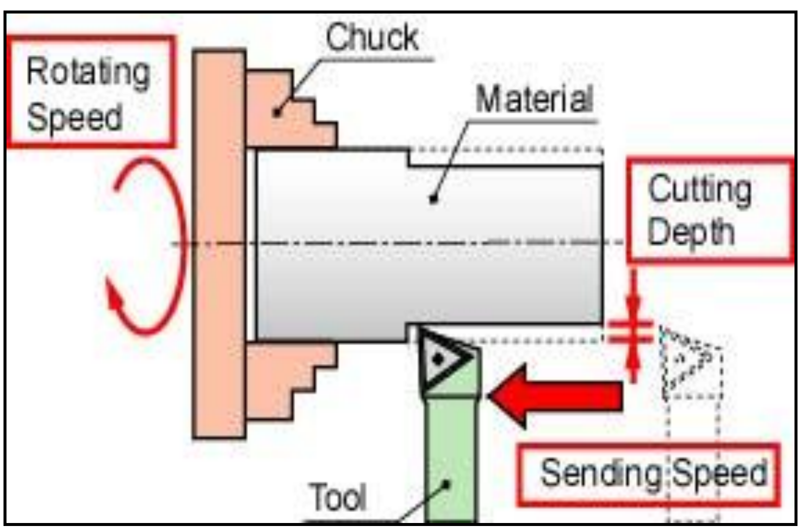

Figure 8: Process Parameters in Turning Operation

1.5 *DYNAMICS OF TURNING*

The relative forces in a turning operation are important in the design of machine tools. The machine tool and its components must be able to withstand these forces without causing significant deflections, vibrations, or chatter during the operation.

There are three principal forces during a turning process: cutting force, thrust force and radial force.

- The **cutting force** acts downward on the tool tip allowing deflection of the work piece upward. It supplies the energy required for the cutting operation.
- The **thrust force** acts in the longitudinal direction. It is also called the feed force because it is in the feed direction of the tool. This force tends to push the tool away from the chuck.
- The **radial force** acts in the radial direction and tends to push the tool away from the work piece.

Although it requires less-skilled labor, the engine lathes do need skilled labor and the production is somewhat slow. Moreover, it can be accelerated by using a turret lathe (In a turret lathe, a longitudinally feedable, hexagon turret replaces the tailstock. The turret, on which six tools can be mounted, can be rotated about a vertical axis to bring each tool into operating position, and the entire unit can be moved longitudinally, either manually or by power, to provide feed for the tools) and automated machines.

1.6 ***TURNING MACHINES***

The turning machines are, of course, every kind of lathes. A lathe is a machine tool used principally for shaping pieces of metal, wood, or other materials by causing the work piece to be held and rotated by the lathe while a tool bit is advanced into the work causing the cutting action. Lathes can be divided into three types for easy identification: Engine Lathe, Turret Lathe, and Special Purpose Lathes. They are heavy duty machine tools and have power drive for all tool movements. They commonly range in size from 12 to 24 inches swing and from 24 to 48 inches center distance, but swings up to 50 inches and center distances up to 12 feet are not uncommon. Many engine lathes are equipped with chip pans and built-in coolant circulating system.

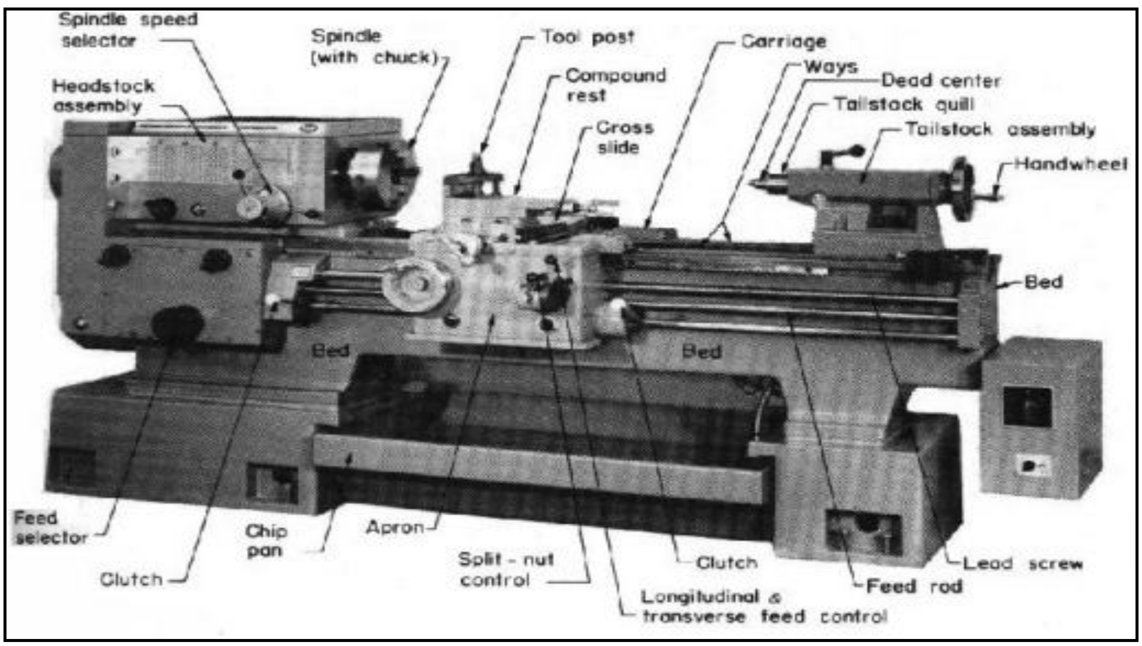

Figure 9: Centre Lathe Used for Turning

1.6.1 PARTS

Almost all lathes have a **BED**, which is (almost always) a horizontal beam (although some CNC lathes have a vertical beam for a bed to ensure that chips fall free of the bed).

At one end of the bed (almost always the left, as the operator faces the lathe) is a **HEADSTOCK**. The headstock contains high-precision spinning bearings. Rotating within the bearings is a horizontal axle, with an axis parallel to the bed, called the spindle.

The spindle is driven, either by foot power from a treadle and flywheel or by a belt or gear drive to a **POWER SOURCE**. In most modern lathes this power source is an integral electric motor, often either in the headstock, to the left of the headstock, or beneath the headstock, concealed in the stand.

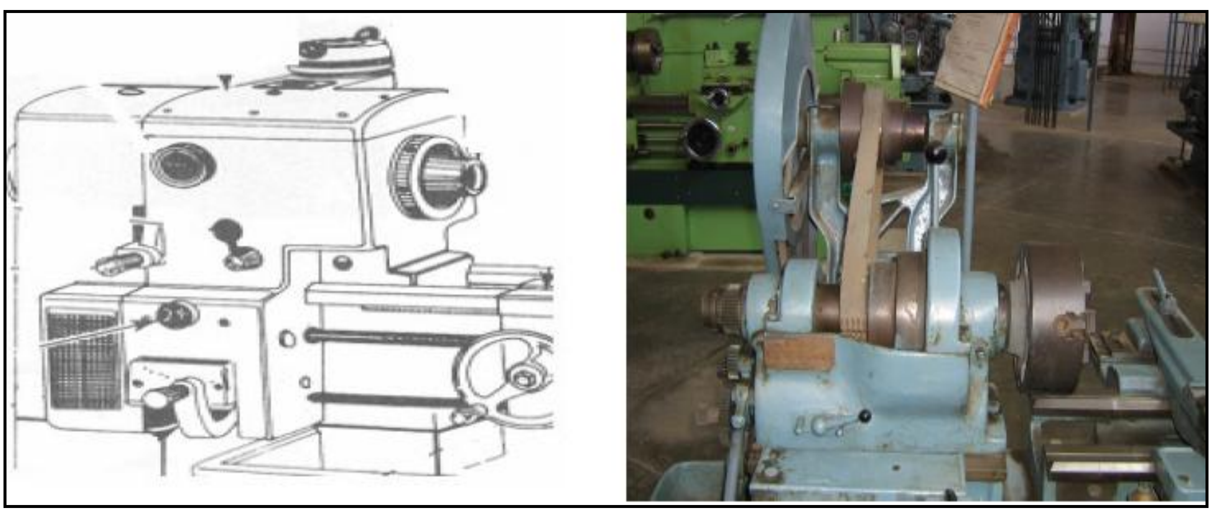

Figure 10: Headstock

In addition to the spindle and its bearings, the headstock often contains parts to convert the motor speed into various spindle speeds. Various types of **SPEED-CHANGING**

MECHANISM achieve this, from a cone pulley or step pulley, to a cone pulley with back gear (which is essentially a low range, similar in net effect to the two-speed rear of a truck), to an entire gear train similar to that of a manual-shift auto transmission.

The counterpoint to the headstock is the **TAILSTOCK**, sometimes referred to as the loose head, as it can be positioned at any convenient point on the bed, by undoing a locking nut, sliding it to the required area, and then relocking it. Its most common uses are to hold a hardened steel centre, which is used to support long thin shafts while turning, or to hold drill bits for drilling axial holes in the work piece.

Metalworking lathes have a **CARRIAGE** (comprising a saddle and apron) topped with a **CROSS-SLIDE**, which is a flat piece that sits crosswise on the bed, and can be cranked at right angles to the bed. Sitting atop the cross slide is usually another slide called a **COMPOUND REST,** which provides 2 additional axes of motion, rotary and linear.

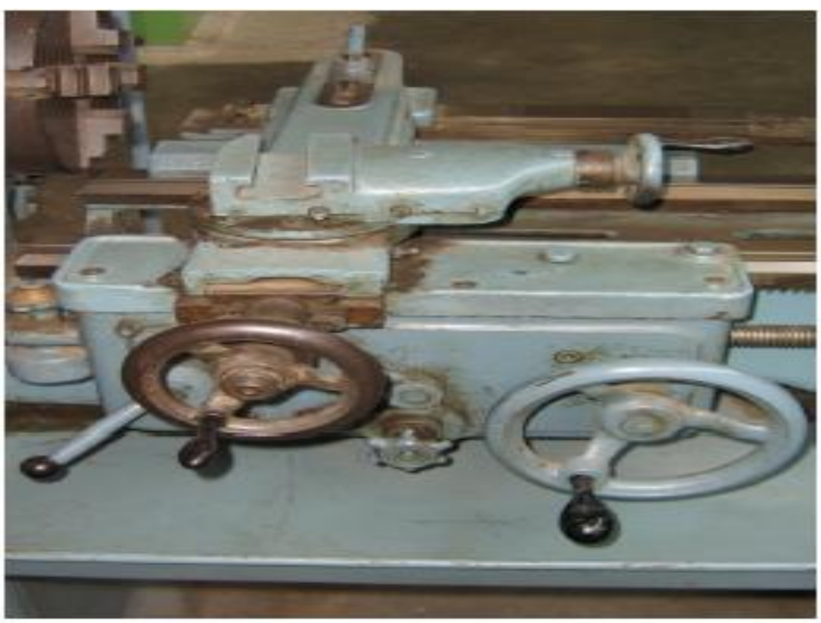

Figure 11: Carriage

At top that sits a **TOOLPOST**; which holds a cutting tool which removes material from the work piece. There may or may not be a lead screw, which moves the cross-slide along the bed.

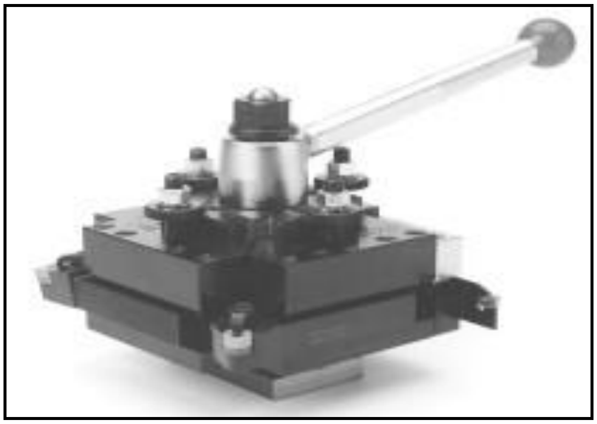

Figure 12: Tool post

1.6.2 VARIETIES

The smallest lathes are "**Jewelers Lathes**" or "**Watchmaker Lathes**", which are small enough that they may be held in one hand. The work pieces machined on a jeweler's lathes are metal.

Smaller metalworking lathes that are larger than jewelers' lathes and can sit on a bench or table, but offer such features as tool holders and a screw-cutting gear train are called **Hobby Lathes**, and larger versions, "**Bench Lathes**". Even larger lathes offering similar features for producing or modifying individual parts are called "**Engine Lathes**".

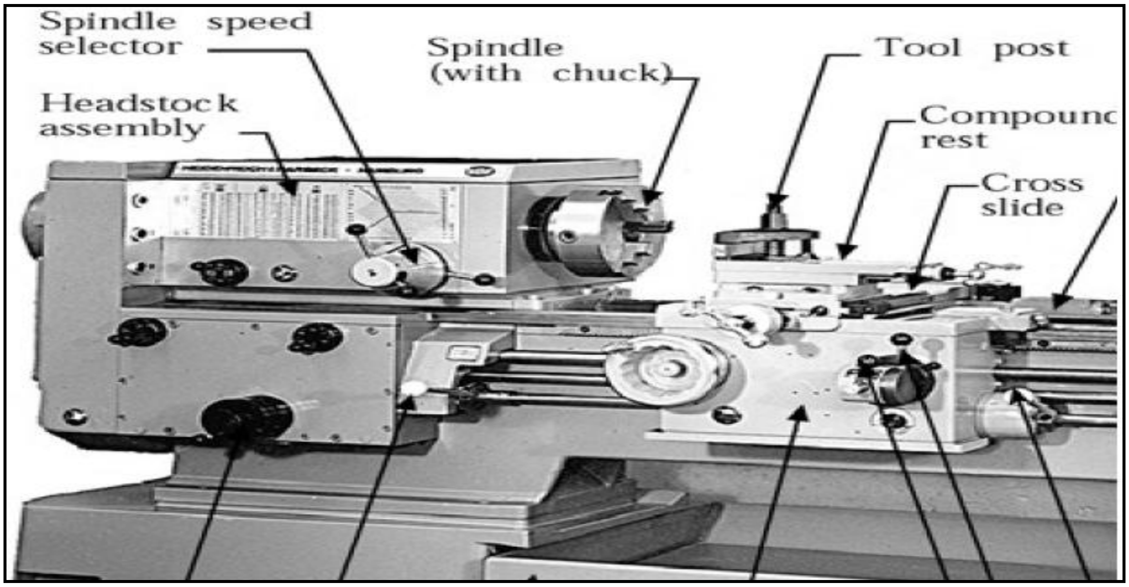

Figure 13: Engine Lathe

Lathes with a very large spindle bore and a chuck on both ends of the spindle are called "**Oil Field Lathes**". Fully automatic mechanical lathes, employing cams and gear trains for controlled movement, are called **Screw Machines**. Lathes that are controlled by a computer are **CNC Lathes**.

Figure 14: CNC Lathe

Lathes with the spindle mounted in a vertical configuration, instead of horizontal configuration, are called **Vertical Lathes** or Vertical Boring Machines. They are used where very large diameters must be turned, and the work piece (comparatively) is not very long.

Lathes with a cylindrical tailstock that can rotate around a vertical axis, so as to present different tools towards the headstock (and the work piece) are **Turret Lathes**.

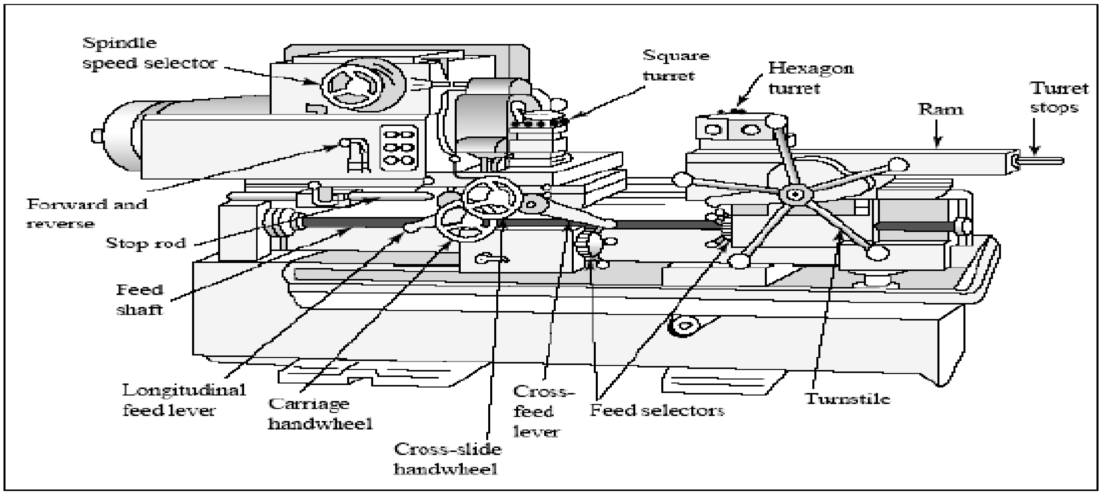

Figure 15: Turret Lathe

A lathe equipped with indexing plates, profile cutters, spiral or helical guides, etc., so as to enable ornamental turning is an **Ornamental Lathe**.

1.7 SURFACE STRUCTURE AND PROPERTIES

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. Surface roughness is an important measure of product quality since it greatly influences the performance of mechanical parts as well as production cost. Surface roughness has an impact on the mechanical properties like fatigue behavior, corrosion resistance, creep life, etc. Before surface roughness, it is also necessary to discuss about surface structure and properties, as they are closely related.

The geometrical characteristics of a surface include,

1. Macro-deviations,
2. Surface waviness,
3. Micro-irregularities.

The surface roughness is evaluated by the height, R_t and mean roughness index R_a f the micro-irregularities.

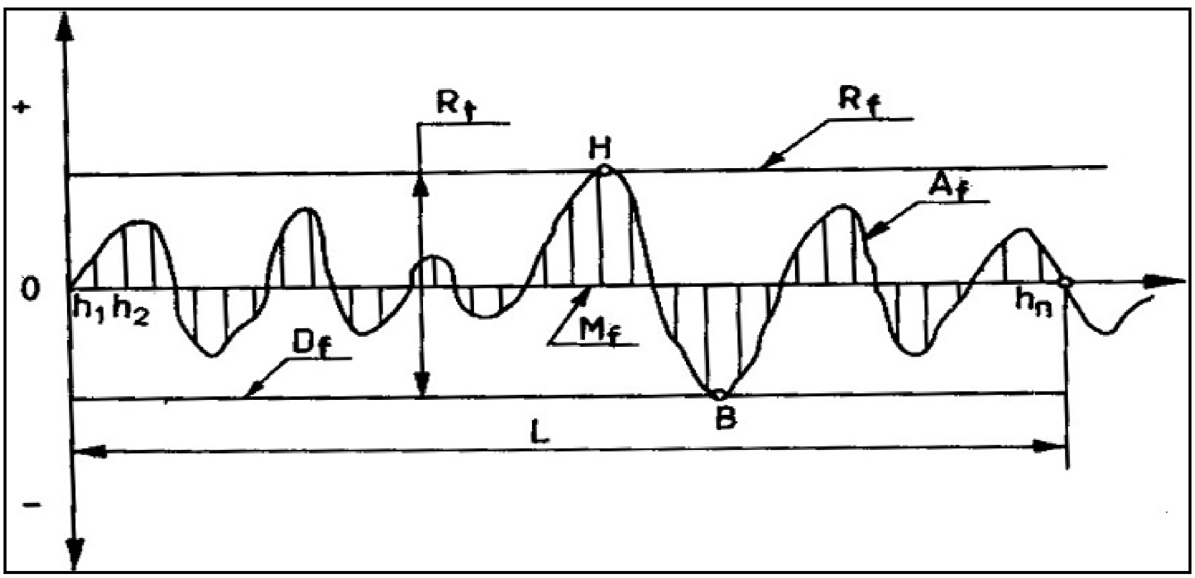

Figure 16: Surface Undulations

Actual Profile, A_f

It is the profile of the actual surface obtained by finishing operation.

Reference Profile, R_f

It is the profile to which the irregularities of the surface are referred to. It passes through the highest point of the actual profile.

Datum Profile, D_f

It is the profile, parallel to the reference profile. It passes through the lowest point B of the actual profile.

Mean Profile, M_f

It is that profile, within the sampling length chosen (L) such that the sum of the material filled areas enclosed above it by the actual profile is equal to the sum of the material void area enclosed below it by the profile.

Peak to valley Height, R_t

It is the distance from the datum profile to the reference profile.

Mean Roughness Index, R_a

It is the arithmetic mean of the absolute value of the highest h_i between the actual and the mean profile.

Upon close examination of the surface of a piece of metal, it can be found that it generally consists of several layers. These layers are briefly outlined here:

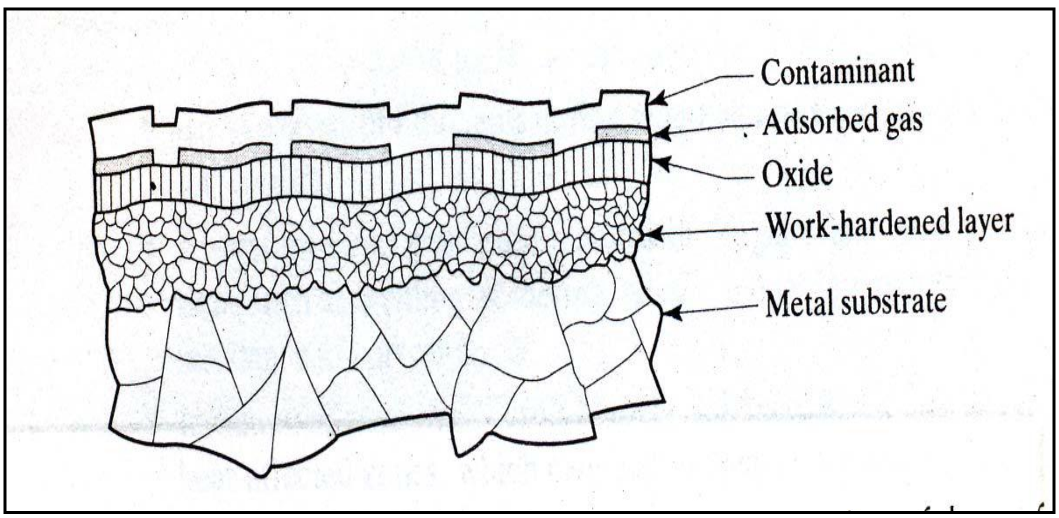

Figure 17: Schematic of a cross-section of the surface structure of metals

1.7.1 SURFACE TOPOGRAPHY

Outermost layers of all machined surfaces display a great number of both macro-geometrical and micro-geometrical deviations from the ideal geometrical surface. Surface roughness refers to deviation from the nominal surface of the third up to sixth order. Order of deviation is defined in international standards. First and second-order deviations refer to form, i.e. flatness, circularity, etc. and to waviness, respectively, and are due to machine tool errors, deformation of the work piece, erroneous setups and clamping, vibration and work piece material inhomogenities. Third and fourth-order deviations refer to periodic grooves, and to cracks and dilapidations, which are connected to the shape and condition of the cutting edges, chip formation and process kinematics. Fifth and sixth-order deviations refer to work piece material structure, which is connected to physical-chemical mechanisms acting on a grain and lattice scale (slip, diffusion, oxidation, residual stress, etc.). Different order deviations are superimposed and form the surface roughness profile.

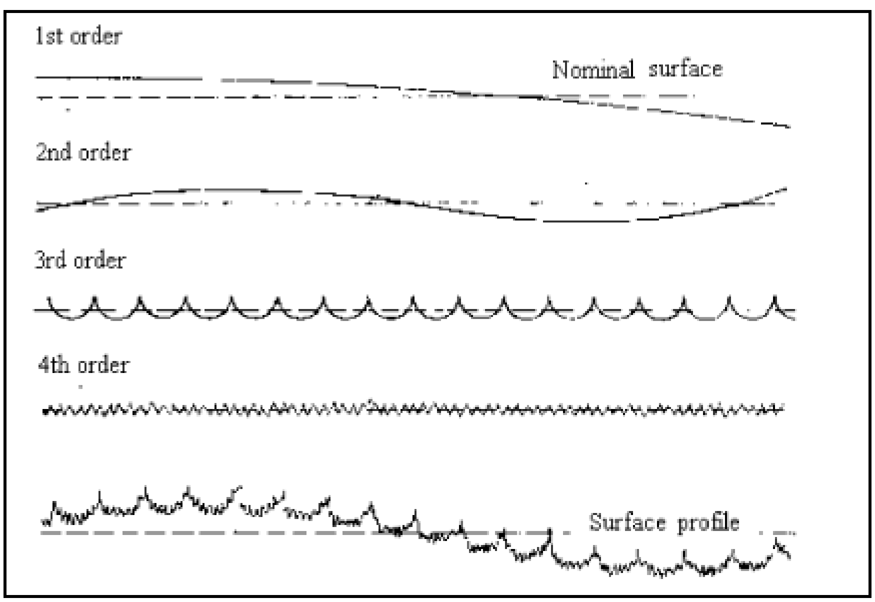

Figure 18: Surface Form Deviations

The principal elements of surfaces are discussed below:

1. **Surface:** The surface of an object is the boundary which separates that object from another substance. Its shape and extent are usually defined by a drawing or descriptive specifications.
2. **Profile:** It is the contour of any specified section through a surface.
3. **Roughness:** It is defined as closely spaced, irregular deviations on a scale smaller than that of waviness. Roughness may be superimposed on waviness. Roughness is expressed in terms of its height, its width, and its distance on the surface along which it is measured.
4. **Waviness:** It is a recurrent deviation from a flat surface, much like waves on the surface of water. It is measured and described in terms of the space between adjacent crests of the waves (waviness width) and height between the crests and valleys of the waves (waviness height). Waviness can be caused by,
   - Deflections of tools, dies, or the work piece,
   - Forces or temperature sufficient to cause warping,
   - Uneven lubrication,
   - Vibration,
   - Any periodic mechanical or thermal variations in the system during manufacturing operations.
5. **Flaws:** Flaws, or defects, are random irregularities, such as scratches, cracks, holes, depressions, seams, tears, or inclusions as shown in Figure.

6. **Lay:** Lay, or directionality, is the direction of the predominant surface pattern and is usually visible to the naked eye. Lay direction has been shown in Figure.

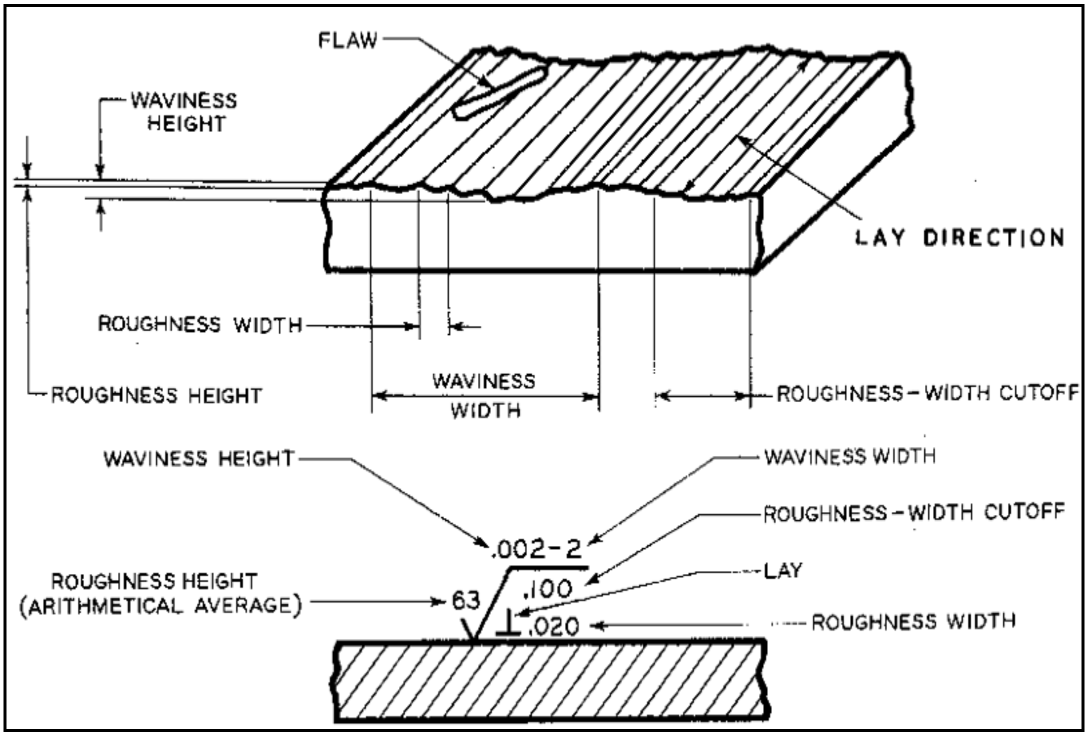

Figure 19: Surface Characteristics

1.7.2 SURFACE FINISH IN MACHINING

The resultant roughness produced by a machining process can be thought of as the combination of two independent quantities:

a. Ideal roughness, and

b. Natural roughness.

a. Ideal roughness

Ideal surface roughness is a function of feed and geometry of the tool. It represents the best possible finish which can be obtained for a given tool shape and feed. It can be achieved only if the built-up-edge, chatter and inaccuracies in the machine tool movements are eliminated completely. For a sharp tool without nose radius, the maximum height of unevenness is given by:

$$R_{max} = \frac{f}{\cot\varphi + \cot\beta}$$

Here f is feed rate, φ is major cutting edge angle and β is the minor cutting edge angle.

The surface roughness value is given by, $R_a = \frac{R_{max}}{4}$

Idealized model of surface roughness has been clearly shown in Figure.

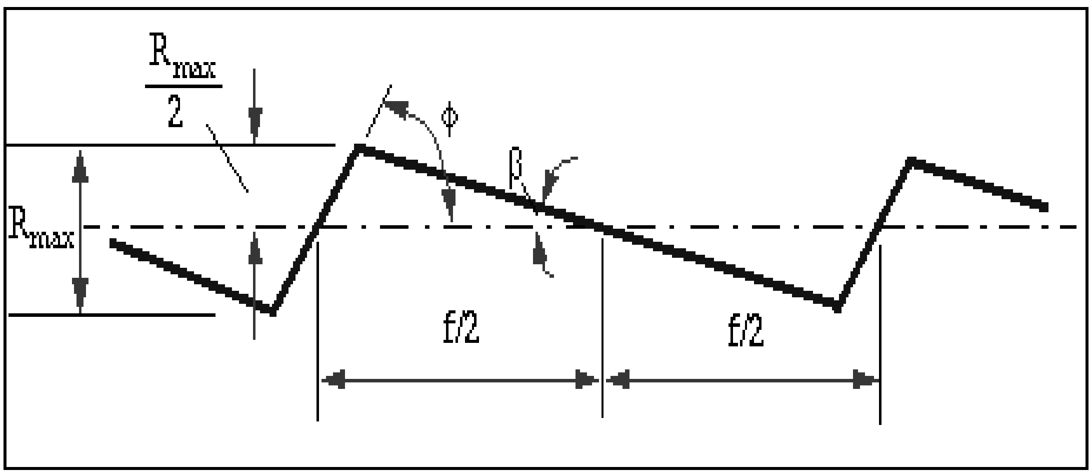

Figure 20: Idealized Model of Surface Roughness

Practical cutting tools are usually provided with a rounded corner, and figure below shows the surface produced by such a tool under ideal conditions. It can be shown that the roughness value is closely related to the feed and corner radius by the following expression:

$R_a = \frac{0.0321 f^2}{r}$ Here r is the corner radius

b. Natural roughness

In practice, it is not usually possible to achieve conditions such as those described above, and normally the natural surface roughness forms a large proportion of the actual roughness. One of the main factors contributing to natural roughness is the occurrence of a built-up edge and vibration of the machine tool. Thus, larger the built up edge, the rougher would be the surface produced, and factors tending to reduce chip-tool friction and to eliminate or reduce the built-up edge would give improved surface finish.

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:

I) machining variables which include:

- a) Cutting speed
- b) Feed, and
- c) Depth of cut

II) 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

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

IV) Quality and type of the machine tool used

V) Auxiliary tooling, and lubricant used and

VI) Vibrations between the work piece, machine tool and cutting tool

1.7.3 ROUGNESS PARAMETERS

Each of the roughness parameters is calculated using a formula for describing the surface. There are many different roughness parameters in use, but Ra is the most common. Other common parameters include R_z, R_q, and R_{sk}. Some parameters are used only in certain industries or within certain countries. For example, the R_k family of parameters is used mainly for cylinder bore linings.

Since these parameters reduce all of the information in a profile to a single number, great care must be taken in applying and interpreting them. Small changes in how the raw profile data is filtered, how the mean line is calculated, and the physics of the measurement can greatly affect the calculated parameter.

By convention every 2D roughness parameter is a capital R followed by additional characters in the subscript. The subscript identifies the formula that was used, and the R means that the formula was applied to a 2D roughness profile. Different capital letters imply that the formula was applied to a different profile. For example, R_a is the arithmetic average of the roughness profile.

Each of the formulas listed in the Table assumes that the roughness profile has been filtered from the raw profile data and the mean line has been calculated. The roughness profile contains n ordered, equally spaced points along the trace, and y_i is the vertical distance from the mean line to the i^{th} data point. Height is assumed to be positive in the up direction, away from the bulk material.

1.7.4 AMPLITUDE PARAMETERS

Amplitude parameters characterize the surface based on the vertical deviations of the roughness profile from the mean line. Many of them are closely related to the parameters found in statistics for characterizing population samples. For example, R_a is the arithmetic average of the absolute values.

The amplitude parameters are by far the most common surface roughness parameters found in the United States on mechanical engineering drawings and in technical literature. Part of the reason for their popularity is that they are straightforward to calculate using a digital computer.

Parameter	Description	Formula
R_a, R_{aa}, R_{yni}	arithmetic average of absolute values	$R_a = \frac{1}{n}\sum_{i=1}^{n} \lvert y_i \rvert$
R_q, R_{RMS}	root mean squared	$R_q = \sqrt{\frac{1}{n}\sum_{i=1}^{n} y_i^2}$
R_v	maximum valley depth	$R_v = \min_i y_i$
R_p	maximum peak height	$R_p = \max_i y_i$
R_t	Maximum Height of the Profile	$R_t = R_p - R_v$
R_{sk}	skewness	$R_{sk} = \frac{1}{nR_q^3}\sum_{i=1}^{n} y_i^3$
R_{ku}	kurtosis	$R_{ku} = \frac{1}{nR_q^4}\sum_{i=1}^{n} y_i^4$
R_{zDIN}, R_{tm}	average distance between the highest peak and lowest valley in each sampling length, ASME Y14.36M - 1996 Surface Texture Symbols	$R_{zDIN} = \frac{1}{s}\sum_{i=1}^{s} R_{ti}$, where s is the number of sampling lengths, and R_{ti} is R_t for the i^{th} sampling length.
R_{zJIS}	Japanese Industrial Standard for R_z, based on the five highest peaks and lowest valleys over the entire sampling length.	$R_{zJIS} = \frac{1}{5}\sum_{i=1}^{5} R_{pi} - R_{vi}$, where R_{pi} R_{vi} are the i^{th} highest peak, and lowest valley respectively.

Table 1: Various Surface Roughness Parameters and Their Formulae

1.8 *MEASUREMENT OF SURFACE ROUGHNES*

Inspection and assessment of surface roughness of machined work pieces can be carried out by means of different measurement techniques. These methods can be ranked into the following classes:

- Direct measurement methods
- Comparison based techniques
- Non contact methods
- On-process measurement

Direct Measurement Methods

Direct methods assess surface finish by means of stylus type devices. Measurements are obtained using a stylus drawn along the surface to be measured. The stylus motion perpendicular to the surface is registered. This registered profile is then used to calculate the roughness parameters. This method requires interruption of the machine process, and the sharp diamond stylus can make micro-scratches on surfaces.

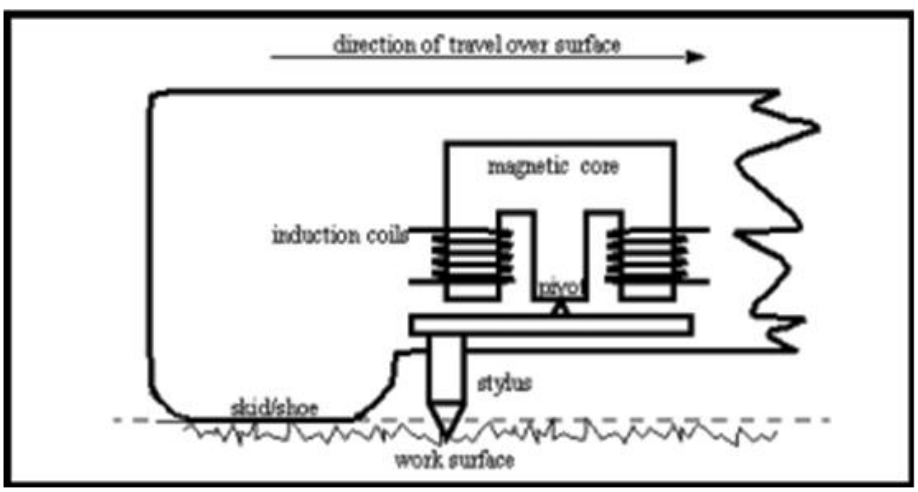

Figure 21: Direct Measurement

Comparison Based Technique:

Comparison techniques use specimens of surface roughness produced by the same process, material and machining parameters as the surface to be compared. Visual and tactile sensors are used to compare a specimen with a surface of known surface finish. Because of the subjective judgment involved, this method is useful for surface roughness R_q >1.6 micron.

Non Contact Methods

There have been some works done to attempt to measure surface roughness using non contact technique. Here is an electronic speckle correlation method given as an example. When coherent light illuminates a rough surface, the diffracted waves from each point of the surface mutually interfere to form a pattern which appears as a grain pattern of bright and dark regions. The spatial statistical properties of this speckle image can be related to the surface characteristics. The degree of correlation of two speckle patterns produced from the same surface by two different illumination beams can be used as a roughness parameter.

On-Process Measurement

Many methods have been used to measure surface roughness in process. For example:

Machine vision

In this technique, a light source is used to illuminate the surface with a digital system to viewing the surface and the data being sent to a computer for analysis. The digitized data is then used with a correlation chart to get actual roughness values.

Inductance method

An inductance pickup is used to measure the distance between the surface and the pickup. This measurement gives a parametric value that may be used to give a comparative roughness. However, this method is limited to measuring magnetic materials.

Ultrasound

A spherically focused ultrasonic sensor is positioned with a non normal incidence angle above the surface. The sensor sends out an ultrasonic pulse to the personal computer for analysis and calculation of roughness parameters.

1.9 FACTORS INFLUENCING SURFACE ROUGHNESS IN TURNING

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

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.

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

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

Engagement of the cutting tool: This factor acts in the same way as the depth of cut.

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.

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.

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.

LITERATURE REVIEW

Lee et al. (2001) used computer vision techniques to inspect surface roughness of a work piece under a variation of turning operations. The surface image of the work piece was first acquired using a digital camera and then the feature of the surface image was extracted. A polynomial network using a self-organizing adaptive modeling method was applied to construct the relationships between the feature of the surface image and the actual surface roughness under a variation of turning operations for predicting surface roughness with reasonable accuracy if the image of the turned surface and turning conditions were given.

Hocheng et al. (2004) studied the surface roughness obtained from the diamond turning of a phosphor–bronze lens mold with various tool nose radii, spindle speeds, feed rates and cutting depths. The surface roughness was measured in the time domain using a Form Talysurf instrument (a stylus-type surface roughness meter) and then transformed into the frequency domain using the fast Fourier transform. Based on the magnitude of the intensity, the tool geometry, low-frequency vibration and the measuring instrument are identified as the main influencing factors of the generated surface roughness.

Sahin et al. (2004) proposed a surface roughness model in the turning of AISI 1040 carbon steel was developed in terms of cutting speed, feed rate and depth of cut using response surface methodology. Machining tests were carried out using PVD-coated ceramic tools under different cutting conditions. The established equation showed that the feed rate was found to be main influencing factor on the surface roughness.

Ozel et al. (2005) utilized neural network modeling to predict surface roughness and tool flank wear over the machining time for variety of cutting conditions in finish hard turning. Regression models were also developed in order to capture process specific parameters. A set of sparse experimental data for finish turning of hardened AISI 52100 steel obtained from literature and the experimental data obtained from performed experiments in finish turning of hardened AISI H-13 steel had been utilized. The data sets from measured surface roughness and tool flank wear were employed to train the neural network models. Trained neural network models were used in predicting surface roughness and tool flank wear for other cutting conditions. Predictive neural network models were found to be capable of better predictions for surface roughness and tool flank wear within the range that they had been trained.

Saparudin et al. (2006) focused on the analysis of optimum cutting conditions to get lowest surface roughness in turning SCM 440 alloy steel by Taguchi method. The results were analyzed using analysis of variance (ANOVA) method. Taguchi method had 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.

Tozu et al. (2006) optimized the machining characteristics of Inconel 718 bars using tungsten carbide and cermet cutting tools based on Taguchi method, the signal-to-noise (S/N) ratio and the analysis of variance (ANOVA). The roundness and flank wear of the ultrasonically and conventionally machined work pieces were measured and compared & the optimal cutting parameters for turning operations were obtained.

Sardinas et al. (2006) presented 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, were simultaneously optimized. The proposed model used a micro genetic algorithm in order to obtain the non-dominated points and build the Pareto front graph. An application sample was developed and its results were analyzed for several different production conditions.

E. Daniel Kirby (2006) discussed an investigation into the use of Taguchi Parameter Design for optimizing surface roughness generated by a CNC turning operation. Controlled factors included spindle speed, feed rate, and depth of cut; and the noise factor was slightly damaged jaws. The noise factor was included to increase the robustness and applicability of this study. The study produced a verified combination of controlled factors and a predictive equation for determining surface roughness with a given set of parameters.

Doniavi et al. (2007) attempted to develop an imperial model with the use of response surface methodology, a widely adopted tool for the quality engineering field. The model showed that the feed rate was found to be main influencing factor on the surface roughness. The results for analysis of variance showed that the first order term of depth of cut was not significant. But the first order term of cutting speed and feed rate were significant.

Ozel et al. (2007) investigated surface finishing and tool flank wear in finish turning of AISI D2 steels (60 HRC) using ceramic wiper (multi-radii) design inserts. Multiple linear regression models and neural network models were developed for predicting surface roughness and tool flank wear. In neural network modeling, measured forces, power and specific forces were utilized in training algorithm. Neural network based predictions of surface roughness and tool flank wear were carried out and compared with a non-training experimental data. These results showed that neural network models are suitable to predict tool wear and surface roughness patterns for a range of cutting conditions.

Ibraheem et al. (2008) proposed statistical package for social sciences (SPSS), to predict surface roughness in turning process. Original length, diameter and selected length were used as independent input variables (parameters), while surface roughness as dependent output variable. On the basis of training data set, different models for surface roughness were developed by multiple regression models. The multiple regression models by using (SPSS) could predict the surface roughness (Ra).

Gusri et al. (2008) applied Taguchi optimization methodology to optimize cutting parameters in turning Ti-6Al-4V ELI with coated and uncoated cemented carbide tools. The turning parameters evaluated was cutting speed, feed rate, depth of cut and type of cutting tool, each at three levels. The results of analysis showed that the cutting speed and type of tool had a very significant effect on the tool life, and the feed rate and type of tool had also a very significant effect on the surface roughness.

Thamizhmanii et al. (2008) analyzed the surface roughness produced by turning process on hard martensitic stainless steel by Cubic Boron Nitride cutting tool. The work piece material was hard AISI 440C martensitic stainless steel. The experiments were designed using various operating parameters like cutting speed, feed rate and depth of cut. It was found that low surface roughness was produced at cutting speed of 225 m/min with feed rate of 0.125 mm/rev and 0.50 mm depth of cut (doc). However, moderate cutting speed of 175 m/min under above feed rate and doc is an ideal operating parameters taking flank wear in to account.

Srikanth et al. (2008) proposed a real coded genetic algorithm (RCGA) to find optimum cutting parameters (speed, feed and depth of cut). This paper explained various issues of RCGA and its advantages over the approach of binary coded genetic algorithm. The results obtained, conclude that RCGA was reliable and accurate for solving the cutting parameter optimization.

Thamma (2008) constructed the regression model to find out the optimal combination of process parameters in turning operation for Aluminium 6061 work pieces. The study highlighted that cutting speed, feed rate, and nose radius had a major impact on surface roughness. Smoother surfaces could be produced when machined with a higher cutting speed, smaller feed rate, and smaller nose radius.

Mahdavinejad et al. (2009) showed the precision of machine tools on one hand and the input setup parameters on the other hand, were strongly influenced in main output machining parameters such as stock removal, toll wear ratio and surface roughness. There were a lot of input parameters which were effective in the variations of these output parameters. In CNC machines, the optimization of machining process in order to predict surface roughness is very important. From this point of view, the combination of adaptive neural fuzzy intelligent system was used to predict the roughness of dried surface machined in turning process.

Adesta et al. (2009) investigated tool wear and surface roughness under different rake angles and different cutting speed. Experiments were carried out by using cermet (CT5015). For every single pass of cutting, surface roughness of work pieces were measured by surface roughness tester. The experimental results showed that by increasing negative rake angles the higher wear occurred shorter duration of tool life and poor surface finish.

Gopalsamy et al. (2009) applied Taguchi method to find optimum process parameters for end milling while hard machining of hardened steel. A L_{16} array, signal-to-noise ratio and analysis of variance (ANOVA) were applied to study performance characteristics of machining parameters (cutting speed, feed, depth of cut and width of cut) with consideration of surface finish and tool life. Results obtained by Taguchi method match closely with ANOVA and cutting speed is most influencing parameter.

Suhail et al. (2010) presented experimental study to optimize the cutting parameters using two performance measures, work piece surface temperature and surface roughness. Optimal cutting parameters for each performance measure were obtained employing Taguchi techniques. The experimental results showed that the work piece surface temperature can be sensed and used effectively as an indicator to control the cutting performance and improves the optimization process. Thus, it is possible to increase machine utilization and decrease production cost in an automated manufacturing environment.

CHAPTER 2

- ***Experimental part***
- ***Methodology***

EXPERIMENTAL PART

The present study has been done through the following plan of experiment.

a) Checking and preparing the Centre Lathe ready for performing the machining operation.

b) Cutting ***Copper*** bars by power saw and performing initial turning operation in Lathe to get desired dimension (of diameter 32mm and length 40mm) of the work pieces.

c) Performing straight turning operation on specimens in various cutting environments involving various combinations of process control parameters like: spindle speed, feed and depth of cut.

d) Measuring surface roughness and surface profile with the help of a portable stylus-type profilometer, *Talysurf* (Taylor Hobson, Surtronic 3+, UK)

The working ranges of the parameters for subsequent design of experiment, based on Taguchi's L_9 Orthogonal Array (OA) design have been selected. In the present experimental study, spindle speed, feed rate and depth of cut have been considered as process variables. The process variables with their units (and notations) are listed in Table 2.

Table 2: Process variables and their limits

	Process variables		
Values in coded form	Spindle Speed A (RPM)	Feed B (mm/rev)	Depth of cut C (mm)
-1	220	0.11	0.5
0	360	0.22	1.0
+1	530	0.44	1.5

Experiments have been carried out using Taguchi's L_9 Orthogonal Array (OA) experimental design which consists of 9 combinations of spindle speed, longitudinal feed rate and depth of cut. According to the design catalogue prepared by Taguchi, L_9 Orthogonal Array design of experiment has been found suitable in the present work. It considers three process parameters (without interaction) to be varied in three discrete levels. The experimental design has been shown in Table 3 (all factors are in coded form). The coded number for variables used in Table 2 and 3 are obtained from the following transformation equations:

Spindle speed: $A = \dfrac{N - N_0}{\Delta N}$ (1)

Feed rate: $B = \dfrac{f - f_0}{\Delta f}$ (2)

Depth of cut: $C = \dfrac{d - d_0}{\Delta d}$ (3)

Here A, B and C are the coded values of the variables N, f and d respectively; N_0, f_0 and d_0 are the values of spindle speed, feed rate and depth of cut at zero level; $\Delta N, \Delta f$ and Δd are the units or intervals of variation in N, f and d respectively.

Table 3: Taguchi's L_9 Orthogonal Array

Sl. No.	Factorial combination		
	A	B	C
1	-1	-1	-1
2	-1	0	0
3	-1	1	1
4	0	-1	0
5	0	0	1
6	0	1	-1
7	1	-1	1
8	1	0	-1
9	1	1	0

Lathe Used:

Machine no in machine shop is -01
Manufactured by - Tussor machine tool India (p) LTD Coimbatore-29' India
Model-180*750
Serial no-700002, manufacturing date-23/10/2007

Cutting Tool Used:

Tool material-HSS
MIRANDA S-400
STS (5/8"*6") 15.88*152.80 mm

Roughness measurement has been done using a portable stylus-type profilometer, *Talysurf* (Taylor Hobson, Surtronic 3+, UK). Table 4 highlights experimental data.

Table 3: Experimental results along with design matrix

Sl. No.	L_{25} OA			Measured roughness parameters			
	A	B	C	R_a μm	R_q μm	R_{ku}	R_{sm} mm
1	-1	-1	-1	1.427	1.650	2.07	0.212
2	-1	0	0	1.237	1.510	2.47	0.157
3	-1	1	1	1.185	1.447	2.25	0.182
4	0	-1	0	1.167	1.372	2.10	0.175
5	0	0	1	1.005	1.252	2.86	0.140
6	0	1	-1	0.881	1.112	3.35	0.142
7	1	-1	1	1.182	1.512	3.14	0.226
8	1	0	-1	0.758	0.934	2.60	0.123
9	1	1	0	0.766	0.942	2.86	0.140

METHODOLOGY FOR OPTIMIZATION

Assuming, the number of experimental runs in Taguchi's OA design is m, and the number of quality characteristics is n. The experimental results can be expressed by the following series: $X_1, X_2, X_3, ..., X_i, ..., X_m$

Here,

$X_1 = \{X_1(1), X_1(2).........X_1(k).....X_1(n)\}$

.

.

.

.

$X_i = \{X_i(1), X_i(2).........X_i(k).....X_i(n)\}$

.

.

.

.

$X_m = \{X_m(1), X_m(2).........X_m(k).....X_m(n)\}$

Here, X_i represents the $i\,th$ experimental results and is called the comparative sequence in grey relational analysis.

Let, X_0 be the reference sequence:

Let, $X_0 = \{X_0(1), X_0(2).........X_0(k).....X_0(n)\}$

The value of the elements in the reference sequence means the optimal value of the corresponding quality characteristic. X_0 and X_i both includes n elements, and $X_0(k)$ and $X_i(k)$ represent the numeric value of $k\,th$ element in the reference sequence and the comparative sequence, respectively, $k = 1, 2, ..., n$. The following illustrates the proposed parameter optimization procedures in detail.

Step 1: Normalization of the responses (quality characteristics)

When the range of the series is too large or the optimal value of a quality characteristic is too enormous, it will cause the influence of some factors to be ignored. The original experimental data must be normalized to eliminate such effect. There are three different types of data normalization according to whether we require the LB (lower-the-better), the HB (higher-the-better) and NB (nominal-the-best). The normalization is taken by the following equations.

(a) LB (lower-the-better)

$$X_i^*(k) = \frac{\min X_i(k)}{X_i(k)}$$

(4)

(b) HB (higher-the-better)

$$X_i^*(k) = \frac{X_i(k)}{\max X_i(k)}$$

(5)

(c) NB (nominal-the-best)

$$X_i^*(k) = \frac{\min\{X_i(k), X_{0b}(k)\}}{\max\{X_i(k), X_{0b}(k)\}}$$

(6)

Here, $i = 1, 2, ..., m;$ $k = 1, 2, ..., n$

$X_i^*(k)$ is the normalized data of the $k\,th$ element in the $i\,th$ sequence.

$X_{0b}(k)$ is the desired value of the $k\,th$ quality characteristic. After data normalization, the value of $X_i^*(k)$ will be between 0 and 1. The series $X_i^*, i = 1, 2, 3, ..., m.$ can be viewed as the comparative sequence used in the grey relational analysis.

Step 2: Checking for correlation between two quality characteristics

Let,

$$Q_i = \{X_0^*(i), X_1^*(i), X_2^*(i), ..., X_m^*(i)\}$$
$$where,\ i = 1, 2, ..., n.$$

(7)

It is the normalized series of the $i\,th$ quality characteristic. The correlation coefficient between two quality characteristics is calculated by the following equation:

$$\rho_{jk} = \frac{Cov(Q_j, Q_k)}{\sigma_{Q_j} \times \sigma_{Q_k}},$$

(8)

here, $j = 1, 2, 3......, n.$ $k = 1, 2, 3, ..., n.,$ $j \neq k$

Here, ρ_{jk} is the correlation coefficient between quality characteristic j and quality characteristic k; $Cov(Q_j, Q_k)$ is the covariance of quality characteristic j and quality characteristic k; σ_{Q_j} *and* σ_{Q_k} are the standard deviation of quality characteristic j and quality characteristic k, respectively.

The correlation is checked by testing the following hypothesis:

$$\begin{cases} H_0 : \rho_{jk} = 0 & (There\,is\,no\,correlation) \\ H_1 : \rho_{jk} \neq 0 & (There\,is\,correlation) \end{cases}$$

(9)

Step 3: Calculation of the principal component score

(a) Calculate the Eigenvalue λ_k and the corresponding eigenvector $\beta_k \, (k = 1, 2, ..., n)$ from the correlation matrix formed by all quality characteristics.

(b) Calculate the principal component scores of the normalized reference sequence and comparative sequences using the equation shown below:

$$Y_i(k) = \sum_{j=1}^{n} X_i^*(j)\beta_{kj}, \quad i = 0, 1, 2, ..., m; k = 1, 2, ..., n. \tag{10}$$

Here, $Y_i(k)$ is the principal component score of the $k\,th$ element in the $i\,th$ series. $X_i^*(j)$ is the normalized value of the $j\,th$ element in the $i\,th$ sequence, and β_{kj} is the $j\,th$ element of eigenvector β_k.

Step 4: Calculation of the Combined Quality Loss (CQL) [Routara et al. (2010)]

Step 5: Optimization (minimization of CQL)

In this study, the multiple quality characteristics are combined to one CQL, thus the traditional Taguchi method can be used to evaluate the optimal parameter combination. Finally the anticipated optimal process parameters are verified by carrying out the confirmatory experiments.

Step 6: Optimization using Taguchi method

The CQL is then optimized (minimized) using Taguchi method. Taguchi's LB (Lower-the-Better) criterion has been explored to maximize the overall grey relational grade.

CHAPTER 3

- ***Evaluation of optimal setting***
- ***Conclusion***

EVALUATION OF OPTIMAL SETTING

Experimental data (Table 3) have been normalized first. Normalized data have been furnished in Table 4. For all surface quality characteristics Lower-the-Better (LB) criterion has been selected. After normalization the data have been checked for correlation. Table 5 shows existence of correlation among the responses (coefficient of correlation became non-zero value). Principal component analysis has been applied to eliminate correlation among the responses. Table 6 represents results of analysis of correlation matrix. Correlated responses have been converted to four independent quality indices denoted as principal components: Z1, Z2, Z3, Z4 respectively. Principal components in all L_9 OA experimental observations have been shown in Table 7. The values of Multi-Response Performance Index (MPI) and Combined Quality Loss (CQL) have been furnished in Table 8 [Routara et al. (2010)].

While calculating MPI it has been assumed that all responses are not equally important. Therefore AP (Accountability Proportion) of individual principal components has been treated as individual priority weight. Optimal parameter setting has been determined from Figure 22. The predicted optimal setting becomes **A1 B2 C3**. Optimal result has been verified through confirmatory test showed satisfactory result.

Table 4: Normalized Response Data

Sl. No.	Normalized Response data			
	R_a µm	R_q µm	R_{ku}	R_{sm} mm
Ideal situation	1.00000	1.00000	1.00000	1.00000
1	0.531184	0.566061	1.00000	0.580189
2	0.612773	0.618543	0.838057	0.783439
3	0.639662	0.645473	0.920000	0.675824
4	0.649529	0.680758	0.985714	0.702857
5	0.754229	0.746006	0.723776	0.878571
6	0.860386	0.839928	0.617910	0.866197
7	0.641286	0.617725	0.659236	0.544248
8	1.000000	1.000000	0.796154	1.000000
9	0.989556	0.991507	0.723776	0.878571

Table 5: Check for correlation

Sl. No.	Correlation between	Pearson's Correlation coefficient	Remarks
1	R_a & R_q	0.994	Correlated
2	R_a & R_{ku}	-0.553	Correlated
3	R_a & R_{sm}	0.845	Correlated
4	R_q & R_{ku}	-0.461	Correlated
5	R_q & R_{sm}	0.850	Correlated
6	R_{ku} & R_{sm}	-0.379	Correlated

Table 6: Eigen value, Eigen vector of major principal components

	Z1	Z2	Z3	Z4
Eigen value	3.1043	0.7080	0.1871	0.0007
Eigen vector	0.558 0.548 -0.358 0.510	-0.089 -0.210 -0.919 -0.323	-0.389 -0.439 -0.142 0.797	0.728 -0.680 0.087 -0.004
Accountability proportion	0.776	0.177	0.047	0.000
Cumulative accountability proportion	0.776	0.953	1.000	1.000

Table 7: Calculated Principal Components

Sl. No.	Z1	Z2	Z3	Z4
Ideal situation	1.258	-1.541	-0.173	0.131
1	0.544498	-1.27255	-0.13472	0.08646
2	0.780419	-1.20766	-0.00451	0.095267
3	0.725961	-1.25625	-0.1242	0.104089
4	0.741064	-1.33366	-0.13131	0.092887
5	1.018631	-1.17272	-0.02345	0.101249
6	1.160925	-1.1006	-0.1008	0.105503
7	0.737911	-0.96843	-0.18049	0.10198
8	1.330977	-1.35367	-0.14405	0.113265
9	1.284478	-1.24522	-0.22276	0.105626

Table 8: Calculated MPI (Multi-response performance index) and combined quality loss

Sl. No.	MPI	CQL	S/N Ratio of CQL
Ideal Situation	0.69532	0.69532	-
1	0.190957	0.190957	14.3813
2	0.391638	0.391638	8.1423
3	0.335152	0.335152	9.4952
4	0.332836	0.332836	9.5554
5	0.581785	0.581785	4.7047
6	0.701334	0.701334	3.0815
7	0.392725	0.392725	8.1182
8	0.786469	0.786469	2.0864
9	0.765882	0.765882	2.3168

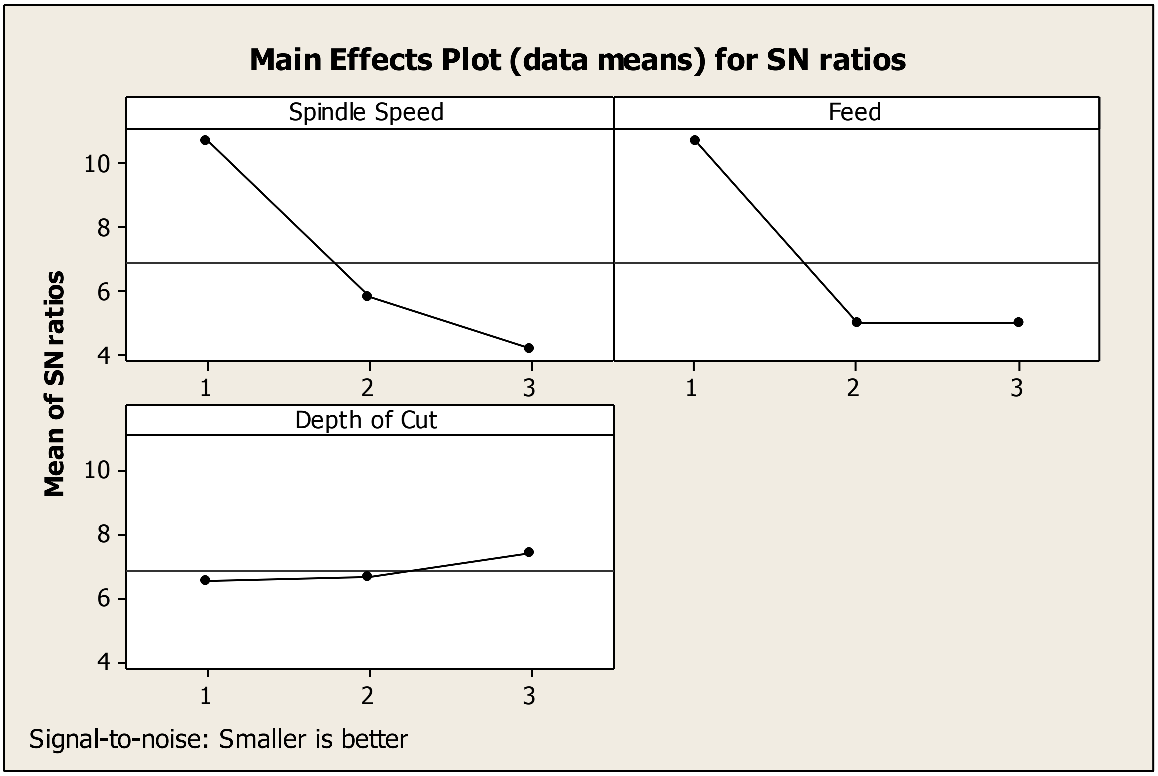

Figure 22: Evaluation of Optimal Setting

CONCLUSION

The foregoing study deals with optimization of multiple surface roughness characteristics of Copper obtained in straight turning operation (using HSS tool) in search of an optimal parametric combination (favorable process environment) capable of producing desired surface quality. The study proposes an integrated optimization approach using Principal Component Analysis (PCA) in combination with Taguchi's robust design methodology. The following conclusions may be drawn from the results of the experiments and analysis of the experimental data in connection with correlated multi-response optimization in cylindrical grinding.

1) Application of PCA has been recommended to eliminate response correlation by converting correlated responses into uncorrelated quality indices called principal components which have been as treated as independent response variables for optimization.
2) Based on accountability proportion (AP); treated as individual response weights, the adopted method can combine individual principal components into a single multi-response performance index MPI to be taken under consideration for optimization. This is really helpful in situations where large number of responses have to be optimized simultaneously.
3) Concept of Combined Quality Loss (CQL) imposes meaningful physical interpretation to the objective function. Moreover, the value of CQL being always positive thus facilitating computation of S/N Ratio required in Taguchi's optimization approach.

4) The said approach can be recommended for continuous quality improvement and off-line quality control of a process/product.

CHAPTER 4

➢ *References*

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