EFFECT OF DRILLING PARAMETERS ON HOLE POSITION TOLERANCES

A Project report submitted in partial fulfillment of the requirement for the award of the degree of

15

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IN
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ABSTRACT

Drilling is one of the important machining process widely used in all type of industry. In aerospace industry the drill hole dimensions are very critical and one has to control the drilling parameters to maintain the desired hole characteristics. In the present project work, focus is made to study the effect of drilling parameters namely spindle speed, feed and drill diameter on Cylindricity, Circularity, Concentricity along X axis and Concentricity along Y axis. Response Surface Method (RSM) based Central Composite Design (CCD) matrix is used to decide the number of experiments. Three factor, three levels are used and total 20 experiments are performed. Empirical mathematical models are developed for the output responses considering significant parameters. Analysis of Variance (ANOVA) is performed for 95% confidence level. Scatter plots are drawn to study the variation of actual and predicted values. Contour plots are studied to indentify the most dominating parameters effecting the output responses.

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NOMENCLATURE

D = Diameter of Drill in mm

N = R.P.M of Drill spindle

V = Cutting speed in meter per minute

f = feed in mm/rev

f_1= feed in mm per minute

t = Depth of cut in mm.

M = total moment of the forces of resistance

T1 = Torque in Newton meter

C = Constant depending upon the material being drilled

W = the web thickness of the drill

B, $C_1$and C_2= Coefficients

F = Thrust Force

x_1,y_1,x_2 , y_2= constants

DOE Design of Experiment

ANNOVA Analysis of Variance

RSM Response Surface Method

N = Number of experimental trails

X = Number of columns of the designed matrix

xμ= value of a factor or interaction in coded form.

Yl=Average

S^2_{ad} = Variance of adequacy or residual variance

S^2y =Variance of optimization parameter of variance

Yavg= Value of response predicted.

DOF = Degree of freedom

N = No of experimental trials

K = No. of independent variables

Y_1= other of the values of response parameter

CMM Coordinate Measuring Machine

CHAPTER – I

INTRODUCTION

This chapter describes about the back ground of drilling process, types of drilling and drill hole characteristics

1.1 The History of Metal Cutting

The history of metal cutting dates from the latter part of the eighteenth century. Before that time machine tools did not exist and the extract from the diary of the English Engineer, Richard Reynolds was attempting to produce a cylinder for fire engineer for drawing the water from a coal pit.

In 1976 James Watt built the first successful steam engine and one of his greatest difficulties in developing this machine was the boring of the cylinder casting. Later Johan Wilkinson has invented the horizontal boring machine. This boring machine was first effective machine tool and it enabled James Watt to produce successful steam engine.

Metal cutting as we know it now started with the introduction of this first machine tool. Today machine tools form the basis of our industry and are used either directly or indirectly in the manufacturing of all products of modern civilization.

1.2 History of Research in Metal Cutting

Research in metal cutting did not start until approximately 70 years after the introduction of the first machine tool. It is not proposed to give a complete history of research in metal cutting but to indicate some of the more important steps that have been made.

According to **Finenie**, who published a historical review of work in metal cutting early research in metal cutting started with**Cocqulhat** in 1851 and was mainly directed towards measuring the work required to remove a given volume of material in drilling. In 1873 tabulations of the work required in metal cutting were presented by **Harting** in a bowl that seems to have been the authority the work on the subject several years.

The scrap removed during the cutting of metal are called chips and the first attempt to explain how chips are formed were made by the time in 1870 and the famous French scientist **Tresca** in 1873, some years later, in 1881, **Mallock** suggested correctly that the cutting process was basically of shearing the work material to form the chip and emphasized the importance of the effect of friction occurring on the cutting tool face as the chip was removed.

Finenie reports that a step backward in the understanding of the metal – cutting process was taken in 1900 when **Reulaux** suggested that a crack occurred ahead of the tool and the process could be linked to splitting of wood.

About this time the famous paper by Taylor was published, which reported the results of 26 years of research investigations and experience. Since 1906 when Taylor's paper was published, empirical and fundamental work has been carried out since and the publication of the well-known paper by Ernst and Merchant in 1941, dealing with mechanics of the process.

1.3 Introduction to Drilling process

It is the process of using a drill bit in a drill to produce holes. Under normal usage, swarf is carried up and away from the tip of the drill bit by the fluting. The continued production of chips from the cutting edges pushes the older chips outwards from the hole. This continues until the chips pack too tightly, either because of deeper than normal holes or insufficient backing off (removing the drill slightly [*breaking the chip*] or totally from the hole [*clearing the bit*] while drilling). Lubricants (or coolants) (i.e. cutting fluid) are sometimes used to ease this problem and to prolong the tool's life by cooling, lubricating the tip and improving chip flow.

1.3.1 Description about Twist drill

The twist drill bit is the type produced in largest quantity today. It drills holes in metal, plastic, and wood.

The twist drill bit was invented by Steven A. Morse of East Bridgewater, Massachusetts in 1861. He received U.S. Patent 38,119 for his invention on April 7, 1863. The original method of manufacture was to cut two grooves in opposite sides of a round bar, then to twist the bar to produce the helical flutes. This gave the tool its name. Nowadays, the drill bit is usually made by rotating the bar while moving it past a grinding wheel to cut the flutes in the same manner as cutting helical gears.

Tools recognizable as twist drill bits are currently produced in diameters covering a range from 0.05 mm (0.002") to 100 mm (4"). Lengths up to about 1000 mm (39") are available for use in powered hand tools.

The geometry and sharpening of the cutting edges is crucial to the performance of the bit. Users often throw away small bits that become blunt, and replace them with new bits, because they are inexpensive and sharpening them well is difficult. For larger bits, special grinding jigs are available. A special tool grinder is available for sharpening or reshaping cutting surfaces on twist drills to optimize the drill for a particular material.

Manufacturers can produce special versions of the twist drill bit, varying the geometry and the materials used, to suit particular machinery and particular materials to be cut. Twist drill bits are available in the widest choice of tooling materials. However, even for industrial users, most holes are still drilled with a conventional bit of high speed steel.

The most common twist drill (the one sold in general hardware stores) has a point angle of 118 degrees. This is a suitable angle for a wide array of tasks, and will not cause the uninitiated operator undue stress by wandering or digging in. A more aggressive (sharper) angle, such as 90 degrees, is suited for very soft plastics and other materials. The bit will generally be self-starting and cut very quickly. A shallower angle, such as 150 degrees, is suited for drilling steels and other tougher materials. This style bit requires a starter hole, but will not bind or suffer premature wear when a proper feed rate is used.

Drills with no point angle are used in situations where a blind, flat-bottomed hole is required. These drills are very sensitive to changes in lip angle, and even a slight change can result in an inappropriately fast cutting drill bit that will suffer premature wear.

- The **Mechanic Drills** used widely by vendors to further describe the length of the drill itself. The actual length x diameter must be found and published.
- The **Jobber Drills** used widely by vendors to further describe the length of the drill itself. The actual length x diameter must be found and published.

Most drills for consumer use have straight shanks. For heavy duty drilling in industry, drills with tapered shanks are sometimes used.

1.3.2 Elements of a Twist Drill

Body. It is the part of the drill that is fluted and relieved.

Shank. It is the part held in the holding device.

The most common types of shanks are the taper shank and the parallel shanks. Small drills up to about 12.7 mm diameter are provided with parallel shanks and the larger size drill have tapered shanks. Tapered shank drill carry a tang at the end of the shank to ensure a positive grip. The straight shank drills are held in a drill machine by a chuck. The jaws of the chuck are tightened around the drill by means of a key or wrench. The point of a drill is the entire cone shaped surface at the cutting end of the drill.

Dead Centre. The dead centre or chisel edge of the drill is the sharp edge at the extreme tip end of the drill. It should always be in the exact centre of the axis of the drill.

Lip. Lip or cutting edge is formed by the intersection of the flank and face. Both the lips of the drills should be of equal length and should be at the same angle of inclination with the drill axis. This will enable to produce a perfectly round smooth and accurate hole. Unequal lips will result in an oversize hole.

Flank. Flank is the surface on a drill point which extends behind the lip to the following flute.

Chisel edge corner. The corner formed by the intersection of a lip and the chisel edge is called chisel edge corner.

Flutes. The grooves in the body of the drill which provides lips.

Twist drill angles. Like any other cutting tool the twist drill is provided with correct tool angles. The various angles are as follows:

Rake angle or helix angle. It is the angle of flute in relation to the work. Smaller the rake angle greater will be the torque required to drive the drill at a given speed. Its usual value is 30^0 although it may very up to 45^0 for different materials.

The rake angle also partially governs the tightness with which the chips curl and hence the amount of space which the chips occupy. Other conditions being the same, a very large rack angle makes a tightly rolled chip, while a rather small rake angle makes a chip tend to curl into a more loosely rolled helix.

Lips clearance angle. It is the angle formed by the flank and a plan at right angle to the drill axis. Lip clearance is the relief that is given to the cutting edges in the order to allow the drill to enter the metal without interference. This angle is 12° in most cases. In order to allow strength and rigidity to the cutting edge the clearance angle should be kept minimum.

Cutting angle or point angle. It is the angle included between the two lips projected upon a plane parallel to the drill axis and parallel to the two cutting lips. It is observed that the best point angle is 118°.

Chisel edge angle. It is the angle included between the chisel edge and the lip as seen from the end of the drill.

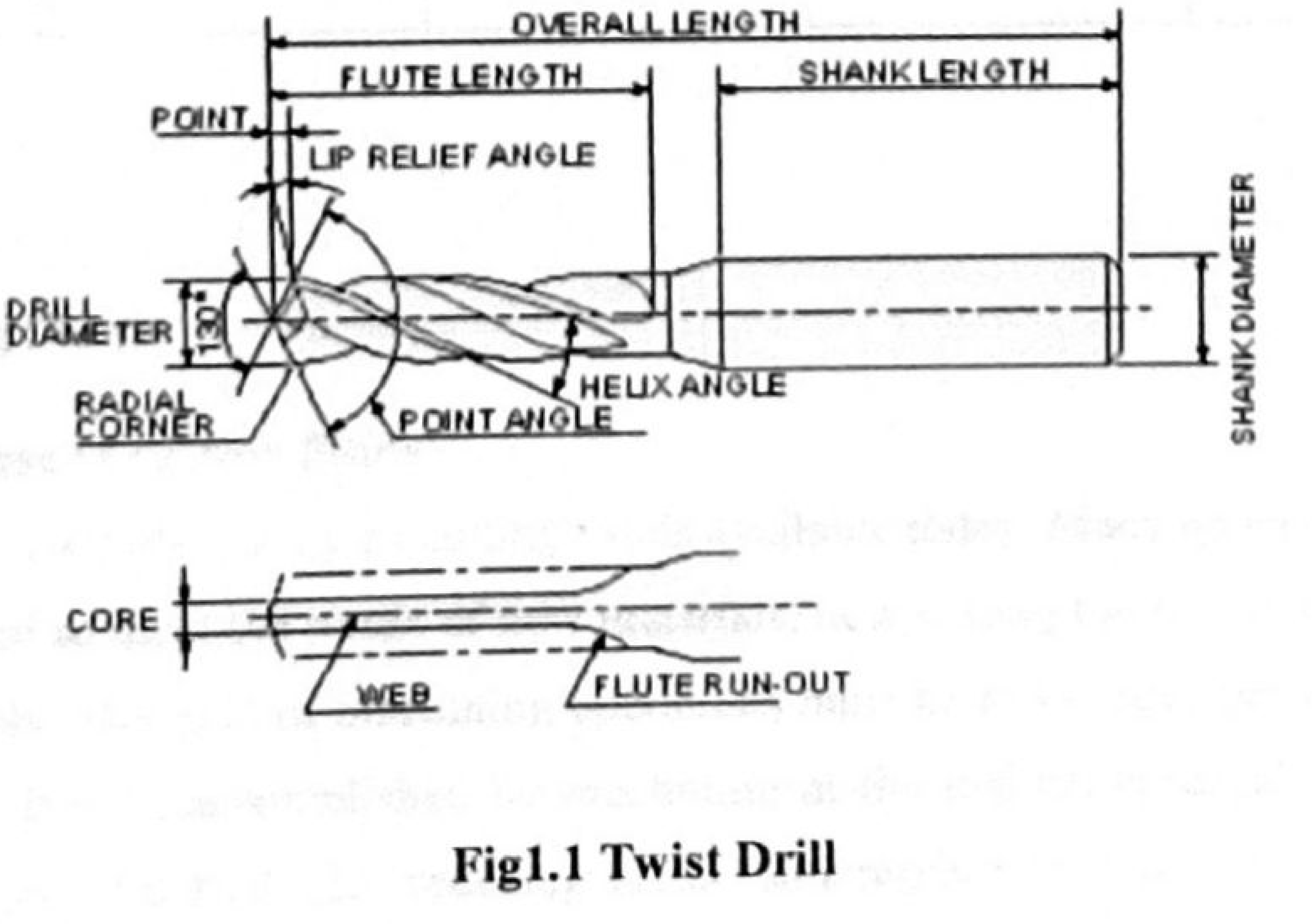


Fig1.1 Twist Drill

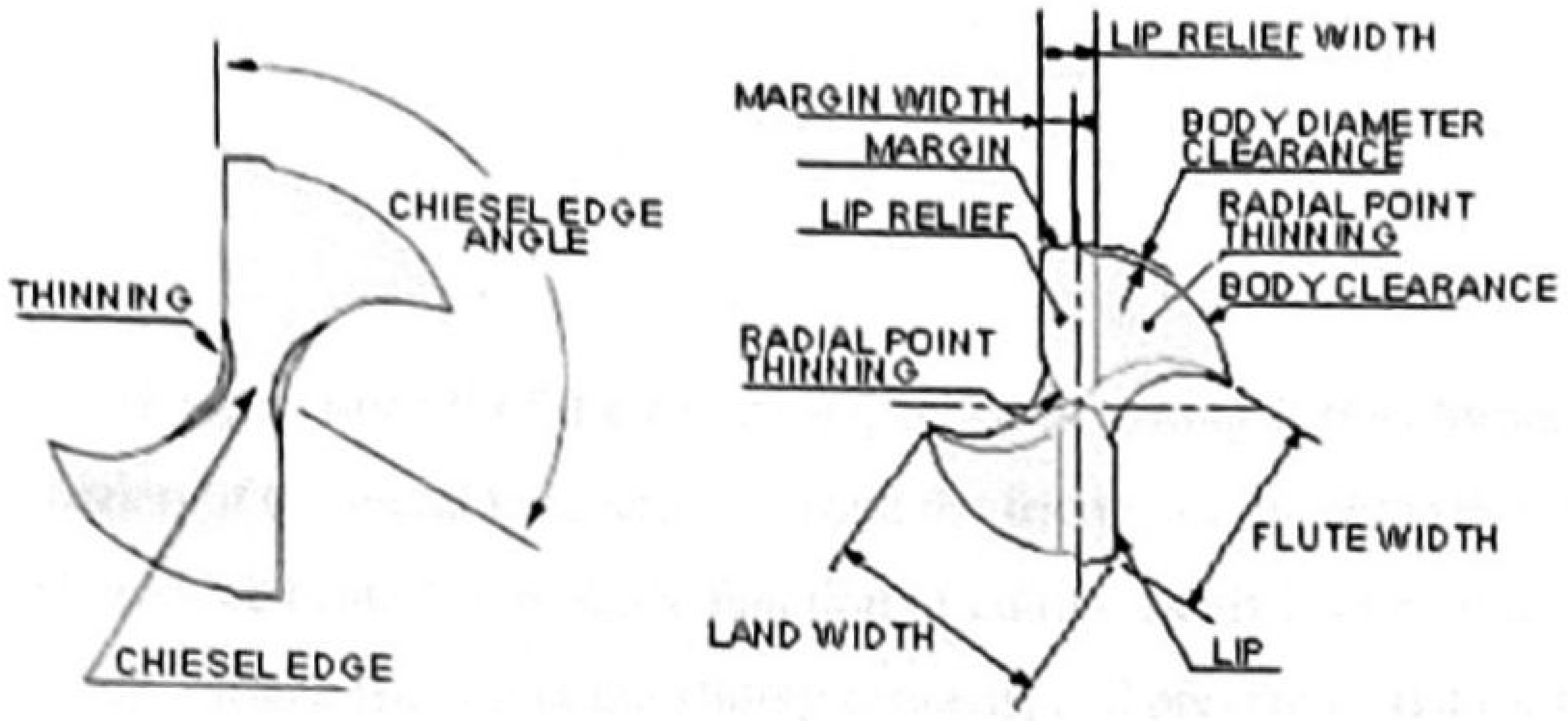


Fig 1.2 Nomenclature of twist drill

Table 1.1 Various angles for a drill are shown in table

Material	*Point angle (Degrees)*	*Lip clearance angle (Degrees)*	*Chisel edge angle (Degrees)*	*Helix angle (Degrees)*
Aluminium	90—140	8—12	120—135	24—48
Brass	111	8—15	120—135	0—27
Copper	100—118	8—15	120—135	28—40
Cast iron hard	118	8—12	120—135	24—40
Steel	118	8—12	120—135	24—32
Stainless Steel	12—135	10—12	120—135	24—32

1.4 Cutting Fluids

1.4.1 Purpose of cutting fluids

There is a wide variety of cutting fluids available today. Many new coolants have been developed to meet the needs of new materials, new cutting tools, and new coatings on cutting tools. The goal of machining operations must be to improve productivity and reduce costs. This is accomplished by machining at the highest practical speed while maintaining practical tool life, reducing scrap, and producing parts with the desired surface quality. Proper selection and use of cutting fluids can help achieve all of these goals.

In machining almost all of the energy expended in cutting is transformed into heat. The deformation of the metal to create chips and the friction of the chip sliding across the cutting tool produce heat. The primary function of cutting fluids is to cool the tool, work piece, and chip, reduce friction at the sliding contacts, and prevent or reduce the welding or adhesion on the contact edges that causes a built-up edge on the cutting tool or insert. Cutting fluids also help prevent rust and corrosion and flush chips away.

Most shops try to reduce the number of different types of fluids that they keep in stock. They try to stock fluids that have long-life, do not need to be changed constantly, don't smoke in use, and don't cause skin irritation. One large consideration is disposal. It is very costly to dispose of cutting fluids.

Cooling

Machining operations create heat. This heat must be removed from the process. The chip helps carry away heat from the tool and work piece. Coolant takes heat from the chips tool, and work piece. To be effective the fluid must be able to transfer heat very rapidly. The fluid absorbs the heat and carries it away.

Lubrication

In a typical machining operation, two-thirds of the heat is created by the resistance of the work piece atoms to being sheared. The friction of the chip sliding over the cutting tool face creates the other one-third of the heat.

Cutting fluid with good lubrication qualities can reduce the friction of the chip sliding over the tool face. The lubrication actually changes the shear angle, which reduces the shear path and produces a thinner chip. Good lubrication also reduces internal friction and heat through less molecular disturbance.

Benefits

Improve Part Quality	The use of cutting fluids reduces friction and heat. The removal of the heat prevents the work piece from expanding during the machining operation, which would cause size variation as well as

	damage to the material's microstructure.
Reduce tooling costs	Proper use of cutting fluids increases tool life, which reduces the tooling costs. Increased tool life also reduces tool changes and downtime which decreases labor costs.
Increase Cutting Speeds and Feeds	Cutting tools reduce friction and heating a machining operation. This allows high speeds and feeds to be used to achieve optimal cutting conditions.
Improved Surface Finishes	Effective use of cutting fluids helps remove the chips. This prevents the chip from being caught between the tool and work piece where it causes scratches and a poor surface finish
Reduces Bacterial Growth	Bacteria can drastically affect cutting oils. Bacteria growth can turn a cutting fluid rancid. Additives in coolants help reduce the effects of bacteria, but it is important that pure water is used for coolant mixing.
Rust and Corrosion Prevention	Cutting fluids should protect the tooling, machine, and work piece against rust and corrosion. Cutting fluids should leave a small residual film that remains after the water has evaporated.

1.4.2 Types of cutting fluids

Cutting fluids can be broken into four main categories: straight cutting oils, water miscible fluids, gasses, and paste or solid lubricants. Two of the three (chemical-based and emulsions) are primarily water. Water quality has a large effect on the coolant. Water that is very hard (high mineral content) can cause rust, stains, and corrosion of machines and work pieces. Water can be deionized to remove the impurities and minerals.

Water is the best fluid for cooling. It has the best ability to carry heat away. Water, however, is a very poor lubricant and causes rust.

Oil is great for lubrication but very poor for cooling. Oil is also flammable. You can see that water and oil have some great strengths but also some great weaknesses. If water and oil are combined, we get the best of both and minimize the weaknesses. Water-soluble fluids have been developed that have good lubrication, cooling ability and rust and corrosion resistance. These fluids are usually mixed in the shop. It is crucial that the mixing directions and concentrations are followed very closely to get the benefits.

1.4.3 Water Miscible

Emulsions

Emulsion is a term that describes soluble oils. An emulsion is a suspension of oil droplets in water. Soluble oils are mineral oils that contain emulsifiers. Emulsifiers are soap-like materials that allow the oil to mix with water. Emulsions (soluble oils) when mixed with water produce a milky white coolant. Lean concentrations (more water-less oil) provide better cooling but less lubrication. Rich concentrations (less water- more oil) have better lubrication qualities but poorer cooling. There are different types of soluble cutting fluids available including extreme pressure soluble oils. These should be used for extreme machining conditions where it is necessary to reduce friction where the tool and work piece contact each other.

Chemical Fluids

Chemical coolants are also miscible cutting fluids. Chemical cutting fluids are pre-concentrated emulsions that contain very little oil. Chemical fluids mix very easily with water. The chemical components in the fluid are used to enhance the lubrication, bacterial control, rust, and corrosion characteristics. There are several types of chemical coolants available, including coolants for extreme cutting conditions.

Inactive chemical cutting fluids are usually clear fluids with high rust inhibition, high cooling, and low lubrication qualities. Active chemical fluids include wetting agents. They have excellent rust inhibition and moderate lubrication and cooling properties. Some contain sulfur or chlorine additives for extreme pressure cutting applications.

Semi-chemical Coolants

Semi-chemical fluids are a combination of a chemical fluid and an emulsion. They have a lower oil content but more emulsifier. This makes the oil droplets much smaller. They have moderate lubrication and cooling and high rust inhibition properties. Sulfur, chlorine, and phosphorous are sometimes added to improve the extreme pressure characteristics.

Straight Cutting Oils

Straight cutting oils are not mixed with water. Cutting oils are generally mixtures of mineral oil and animal, vegetable, or marine oils to improve the wetting and lubricating properties. Sulfur, chlorine, and phosphorous compounds are sometimes added to improve the lubrication qualities of the fluid for extreme pressure applications. There are two main types of straight oils: active and inactive.

Inactive Straight Cutting Oils

Inactive oils contain sulfur that is very firmly attached to the oil. Very little sulfur is released in the machining process to react with the work piece. Mineral oils are an example of straight oils. Mineral oils provides excellent lubrication, but are not very good at heat dissipation (removing heat from the cutting tool and work piece). Mineral oils are particularly suited to nonferrous materials, such as aluminum, brass, and magnesium. Blends of mineral oils are also used in grinding operations to produce high surface finishes on ferrous and nonferrous materials.

Active Straight Cutting Oils

Active oils contain sulfur that is not firmly attached to the oil. The sulfur is released during the machining operation to react with the work piece. These oils have good lubrication and cooling properties. Special blends with higher sulfur content are available for heavy duty machining operations. They are recommended for tough low carbon and chrome-alloy steels. They are widely used in thread cutting. They are also good for grinding as they help prevent the grinding wheel from loading up. This increases the life of the grinding wheel.

Gasses

Cutting oils and water miscible types of cutting fluids are the most widely used. Gasses are sometimes use. Compressed air and inert gasses are sometimes used. Carbon dioxide, Freon, and nitrogen are also used sometimes.

Paste and Solid Lubricants

Waxes, pastes, soaps, graphite, and molybdenum disulfide may be used. These are generally applied directly to the work piece or tool, or in some cases, impregnated directly into a tool, such as a grinding wheel. One example would be lard. Many experienced journeymen recommend lard for tapping.

1.5 Twist drill failure

A twist drill will suffer an early failure or produce holes that are dimensionally inaccurate, out of round and poor finish for the following general reasons:

- Incorrect speed and feeds.
- Incorrect grinding of the point
- Mishandling.

1.6 Drill Specifications

According to Indian Standard System, twist drills are specified by the diameter, the I.S. number, the material and the series to which they belong.

The drills are made in three types:

Type N— for normal low carbon steel.

Type H— for hard materials.

Type S— for soft and tough materials.

For example a parallel shank twist drill 12 mm diameter and made up of high speed steel and conforming to IS: 5101 with a point angle of 118° and of N-type is designated as 12.00—IS : 5101 HS-N-118.

Unless otherwise mentioned in the designation it should be assumed that drill type is N and point angle is 118°.

Drill Size. In metric system the drills are made in diameters from 0.2 mm to 100 mm.

1.7 Factors effecting Drill Torque and Trust forces

Cutting speed: It is the peripheral speed of a point on the surface of the drill in contact with the work piece. It is usually expressed in metres per minute.

Let D = Diameter of drill in mm.

N = R.P.M. of drill spindle.

V = Cutting speed in metre per minute.

$V = \pi DN/100$ metre per minute.

Cutting speed mainly depends upon the following factors:

Type of material to be drilled.

Type of material of drill. Twist drill made of high speed steel can be operated at about twice the speed of drill made of high carbon steel.

Type of finish required.

Type of coolant used.

Capacity of machine and tool life.

Table 1.2 Cutting speed for high speed steel drill.

Material being drilled	*Cutting speed (m/min)*
Aluminium	70—100
Brass	35—50
Phosphor Bronze	20—35
Grey Cast Iron	25—40
Copper	35—45
Mild Steel	30—40
Alloy Steel (High tensile)	5—8

Feed. It is the distance the drill moves into the work at each revolution of the spindle. It is expressed as millimeter per revolution:

It may also be expressed as feed per minute.

Let N = R.P.M. of drill spindle.

f = feed in mm/rev.

f_1 = feed in mm per minute.

$= N.f.$

Table 1.3 Feed for high speed steel drill of various diameters.

Drill diameter (mm)	*Feed (mm/rev.)*
1.0—2.5	0.04—0.06
2.6—4.5	0.05—0.10
4.6—6.0	0.075—0.15
6.1—12.00	0.75—0.25
12.1—15.0	0.20—0.30
15.1—18.0	0.23—0.33
18.1—21.0	0.26—0.36
21.1—25	0.28—0.39

A twist drill gives satisfactory performance if it is run at correct cutting speed and feed.

The following factors help in running the drill at correct cutting speed and feed.

The work is rigidly clamped.

The machine is in good condition.

A coolant is used if required.

The drill is correctly selected and ground for the material being cut.

The selection of drill depends upon the following.

Size of drill hole

Material of workpiece

Point angle of drill.

The rates of feed and cutting speed for twist drill are lower than most other machining operations because of the following reasons.

The twist drill is weak compared with other cutting tools.

It is relatively difficult for the drill to eject chips.

It is difficult to keep the cutting edges cool when they are enclosed in the hole.

Depth of cut. It is equal to one half of the drill diameter.

D = Diameter of drill in mm.

t = Depth of cut in mm.

= D/2 mm.

1.8 Forces Acting on a Drill

All the elements of a drill are subject to certain forces in drilling. Resolving the resultant forces of resistance to cutting at each point of the lip we obtain three forces F_Z F_V and F_H acting in directions mutually perpendicular to each other. The horizontal forces F_H acting on both lips are considered to counter balance each other. The vertical force F_V also called as thrust force comprises of the forces $F_{V1}F_{V2}$ F_C and Fm. (The forces Fc and F_m are not shown).The force F_{V1}, acts on the web. This force is quite large and is about 60% of the total thrust force. This force F_{V2} act on each of the two lips and forms the real cutting force which depends upon the work material, cutting variables and cutting point geometry and is about 37% of total thrust force. The F_C and E_m are of smaller magnitude. The force F_C is due to the rubbing of the chips, flow from the hole against the sides of the hole and flutes on the drill. This force is about 1% of the total thrust force. The force F_M is due to therubbing action of margin of the drill against the sides of the hole and is about 2% of thrust force.

In order that the drill to penetrate into the work piece the thrust force F applied to it by the machine must overcome the sum of resistances acting along the drill axis.

$F>\sum (F_{V1}+2F_{V2}+F_C+F_m)$

The force F_Z sets up the moment of resistance (M_r)

$M_r = F_Z S$

The total moment of the forces of resistance (M) to cutting is made up of the following moments.

Moment of forces F_Z i.e.M_R

Moment of forces due to scraping and friction on the chisel edge (M_c)

Moment of the friction forces on the margins (M_m)

Moment of the forces of friction of the chip on the drill and on the machined surface (M_d)

$M=M_r +M_c+ M_m+ M_d$.

The total moment of resistance should be overcome by the available torque of the drilling machine.

1.9 Power of Drilling

When a drill is cutting it has to overcome the resistance offered by the metal and a twisting effort is necessary to turn it. The effort is called turning moment or torque on the drill. The torque required to operate a drill depends upon various factors. The relationship between torque, diameter of drill and feed is as follows:

$T_1 = C.f^{0.75} D^{1.8}$ newton meters

Where $T1$ = Torque in Newton metre

f = Drill feed in mm/rev.

D = Diameter of drill in mm.

C = Constant depending upon the material being drilled.

Table 1.4 The values of C are given in table for different materials

Material to be drilled	*Value of C*
Aluminium	0.11
Soft brass	0.084
Cast Iron	0.07
Mild steel	0.36
Carbon tool steel	0.4

Power $(P) = 2\pi N T_1/60000$ kW

Where N = Drill speed in R.P.M.

1.10 Mechanics of Drilling process

Drilling is the most commonly used process. However, it is still difficult to give an exact analysis for the torque and thrust in drilling. Several researchers have found empirical relationship for thrust and torque in drilling applicable to different work materials, drill geometry and drilling conditions. In fact, the thrust and torque have been expressed in exponential form in terms of drill feed, drill diameter and web thickness. The general functions are of the type given below.

$$F \text{ (Thrust)} = C_1 f^{x_1} (B.D + W/D)^{y_1}$$

$$M \text{ (Torque)} = C_2 f^{x_2} D^{y_2}$$

Where D is the drill diameter, f the drill feed, W the web thickness of the drill, and the coefficient B, C_1 and C_2 as well as the exponents x_1, y_1, x_2 and y_2 are constants for a particular work material. For some materials these functions are given below.

For nonferrous materials, the thrust force may be expressed in the form

$$F = C. f^{a} D^{b}$$

For instance, for

$$F = 196.2^{1} DN$$

$M = 0.1265 f^{3} D N m$

Table 1.3 Point, Flute Helix and Relief Angles HSS Drills

Work piece Material	Point angle (degrees)	Helix angle Of flute(degrees)	Relief angle (degrees)
Aluminium alloys	90-140	24-45	12-15
Brasses	118-125	8-12	12-15
Cast irons(soft)	90-100	18-30	8-12
(hard)	118-150		
Copper	100-118	24-40	12-15
Plastics(soft)	80	30-40	12-15
(hard)	140	12	8-10
Steels(low strength)	118	30	12-15
Steel(Medium strength)	120	25	10-12

1.11 Surface Roughness

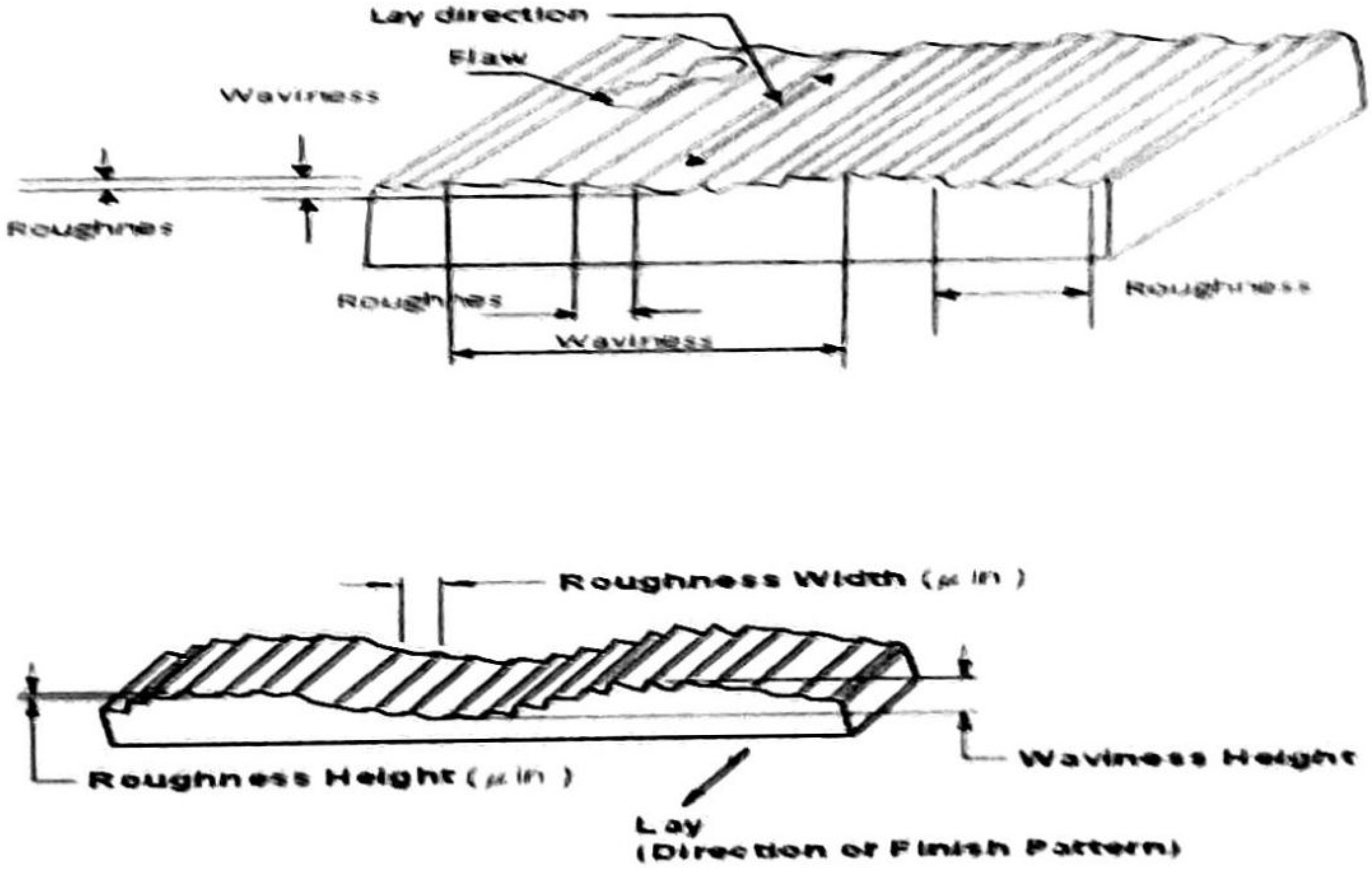


Figure 1.3 Surface structure after cutting process

Surface roughness is the measure if the finer surface irregularities in the surface texture. The final surface depends on the rotational speed of the cutter, velocity of traverse, feed rate and mechanical properties of work pieces being machined. Surface roughness also plays a significant role in determining and evaluating the surface quality of a product. Because surface roughness affects the functional characteristic of products such as fatigue, friction, wearing, light reflection, heat transmission, and lubrication, the product quality is required to be at the high level (Ibraheem 2007). While surface roughness also decreases, the product quality also increases. Figure 2.1 show the surface roughness structure after any cutting process with their terminology.

The surface roughness describes the geometry of the surface to be machined and combined with surface texture. The formation of surface roughness mechanism is very complicated and mainly depends on machining process (Benardos & Vosniakos, 2003; Petropoulos et al., 2006).

1.11.1 Surface roughness terminology

Roughness -Roughness consists of surface irregularities which result from the various machining process. These irregularities combine to form surface texture

Roughness height -It is the height of the irregularities with respect to a reference line. It is measured in millimeters or microns or microfiches. It is also known as the height of unevenness.

Roughness width -is the distance parallel to the nominal surface between successive peaks which constitute the predominate pattern of the roughness.

Roughness width cut off -is the greatest spacing of respective surface irregularities to be included in the measurement of the average roughness height. It should always be greater than the roughness width in order to obtain the total roughness height rating.

Lay -the direction of predominant surface pattern produced and it reflects the machining operation used to produce it.

Waviness -The irregularities which are outside the roughness width cut off values. Waviness is the widely spaced component of the surface texture. This may be the result of work piece or tool deflection during machining, vibrations or tool run out.

Waviness width - Waviness height is the peak to valley distance of the surface profile, measured in millimeters.

1.11.2 Surface finish in machining

Ideal roughness –

It is a function of only feed and geometry. 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. Natural roughness -In practice, it is not usually possible to achieve conditions such as those described above, and normally the natural surface roughness forms as larger proportion of the actual roughness. One of the main factors contributing to natural roughness is the occurrence of a built-up edge. 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.

1.12 Cylindricity

Cylindricity applies to all cross-sections of a cylindrical surface simultaneously. The surface must lie between the two cylindrical surfaces which bound the tolerance zone and are determined by a best-fit nominal cylinder

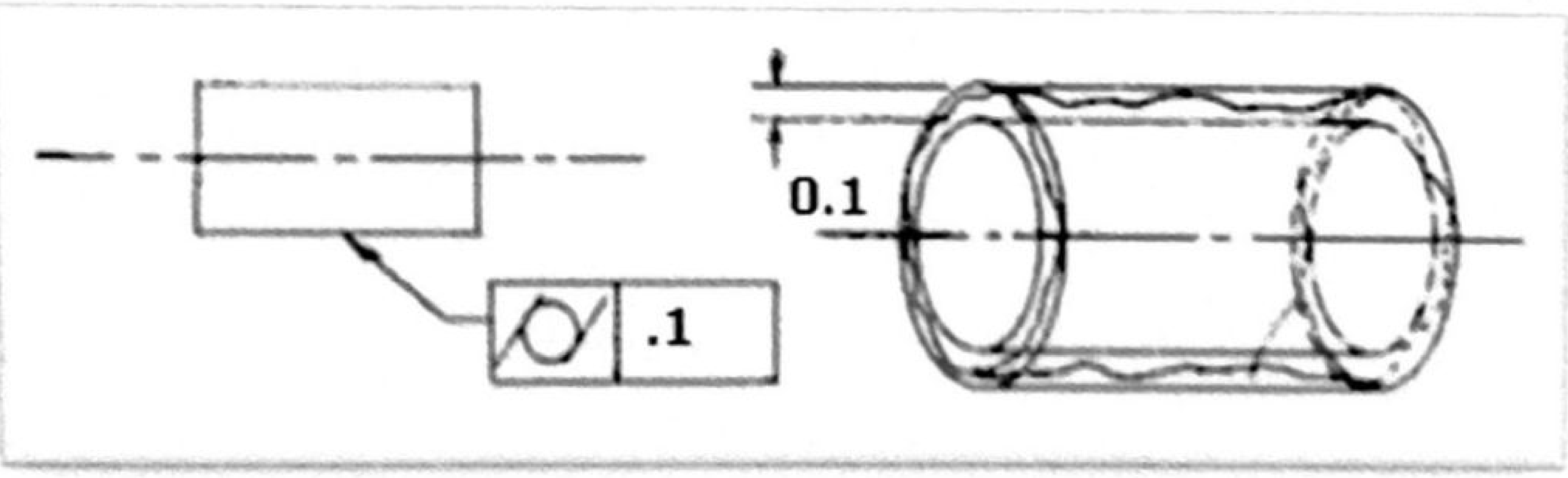


Fig 1.4 Cylindricity

1.13 Concentricity

Concentricity is the condition in which the axes of all cross-sectional elements of a surface of revolution are common to the axis of a datum feature. Because the location of the datum axis is difficult to find, it is easier to inspect for cylindricity or runout.

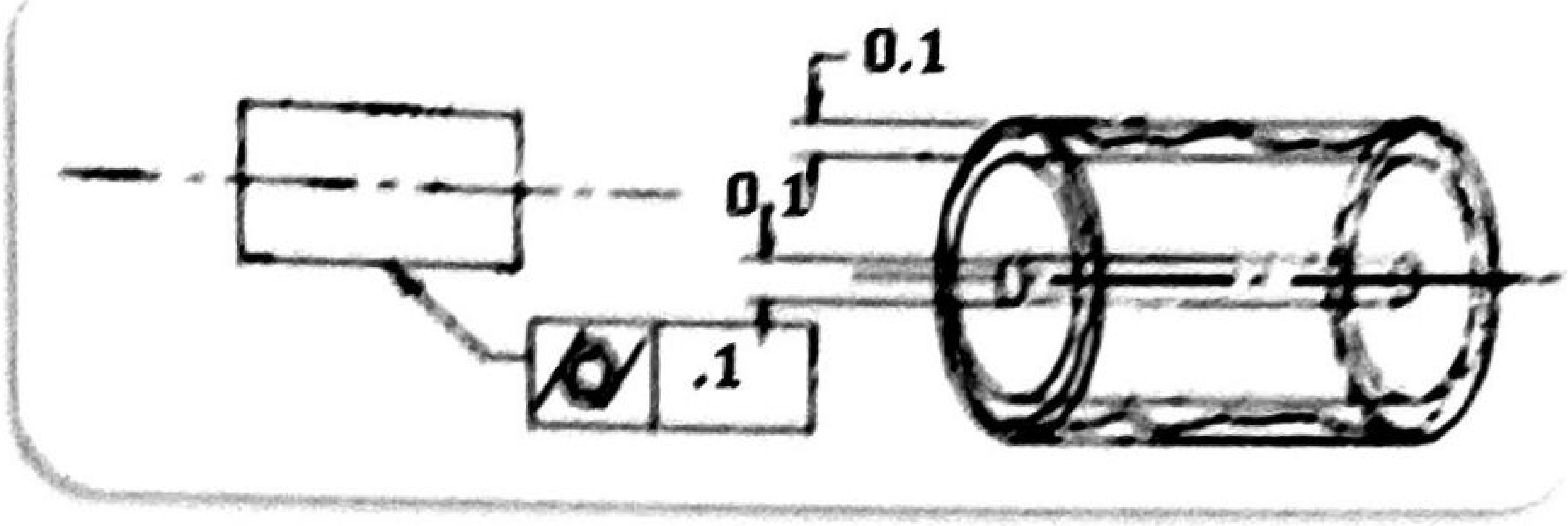


Fig 1.5Concentricity

1.14 Eccentricity

It is the term used to describe the position of the center of a profile relative to some datum point. It is a vector quantity in that it has magnitude and direction. The magnitude of the eccentricity is expressed simply as the distance between the datum point and profile center. The direction is expressed as simply as an angle from the datum point to the profile center.

LITERATURE REVIEW

This chapter deals with different experiments that are conducted by different people regarding the present project.

RuiLia et al.[1] conducted experiments of high-throughput drilling of Ti–6Al–4V at 183m/min cutting speed and 156mm^3/s material removal rate (MRR) using a 4 mm diameter WC–Co spiral point drill were conducted. The drilling process parameters, including cutting speed, feed, and fluid supply, were studied to evaluate the effect on drill life, thrust force, torque, energy, and burr formation. The tool wear Mechanism, hole surface roughness, and chip light emission and morphology for high-throughput drilling were investigated.

Samar Singh et al. [2] Developed an electric Discharge Drill Machine (EDDM) is a spark erosion process to produce micro holes in conductive materials. This process is widely used in aerospace, medical, dental and automobile industries In this research paper a brass rod 2 mm diameter was selected as a tool electrode. The experiments generate output responses such as material removal rate (MRR). The best parameters such as pulse on-time, Pulse off-time and water pressure were studied for best machining characteristics. This investigation presents the use of Taguchi approach for better MRR in drilling of Al-7075.

Noorul Haq et al. [3] analyzed an approach for the optimization of drilling parameters on drilling Al/SiC metal matrix composite with multiple responses based on orthogonal- oral array with grey relational analysis. Experiments are conducted on LM25-based aluminium alloy reinforced with green bonded silicon carbide of size 25 μm (10% volume fraction). Drilling tests are carried out using TiN coated HSS twist drills of 10 mm diameter under dry condition. Based on the grey relational grade, optimum levels of parameters have been identified and significant contribution of parameters is determined by ANOVA.

P. N. E. Naveen et al. [4] studied about composite materials which are being used in automobiles. It is difficult to machine hemp fiber composite materials with high efficiency to yield good quality products automotive industries. The present work investigates the effects of the drilling parameters, speed and feed, on the damage factor in drilling composites glass, hemp & sandwich fibers with different fiber volume fractions (i.e10%,20%&30%).

The objective of this paper is to decrease the damage factor of composite materials with different fiber volume fractions, by varying drill parameters such as speed and feed. The composite material having the size of 100×50×3 mm and using the drill diameter as 6 mm.

Yogendra Tyagi et al.[5] the drilling of mild steel with the help of CNC drilling machining operation with tool use high speed steel by applying taguchi methodology has been reported. The signal-to-noise ratio applied to find optimum process parameter for CNC drilling machining .A L9 orthogonal array and analysis of variance (ANOVA) are applied. Results obtained by taguchi method and signal-to-noise ratio match closely with (ANOVA) and the feed are most effective factor for MRR. Multiple regression equation is formulated for estimating predicted value surface roughness and MRR.

R. Vimal Sam Singh et al. [6] analyzed on Glass fiber reinforced plastics which are finding increased applications in various engineering fields such as aerospace, automotive, electronics and other industries. Drilling is one of the most frequently practiced machining processes in industries owing to the need for component assembly in mechanical structures. In this work, experiments were conducted using 8 Facet Solid Carbide drills based on L27 Orthogonal Array. The process parameters investigated are spindle speed, feed rate and drill diameter. Fuzzy rule based model is developed to predict thrust force and torque in drilling of GFRP composites. The results indicated that the model can be effectively used for predicting the response variable by means of which delamination can be controlled.

P. Stringer et al. [7] explained One of the most significant problems encountered in machining, particularly in drilling, is that of burr formation. Burrs usually comprise of work piece material which has been plastically deformed during the machining process and projects beyond the desired edge of the work piece. The adverse effects of burrs depend on the component application but may include; stress concentration and related fatigue failure and increased wear on components and tools involved in the manufacture of the part. The minimization or eradication of burrs produced during the drilling process is therefore of the utmost importance. Currently there is a focus on reducing burr formation through optimization of process control parameters and drill geometry.

Majid Tolouei-Rad et al. [8] analyzed that drilling is the most common machining operation and it forms the highest machining cost in many manufacturing activities including automotive engine production. The outcome of this operation depends upon many factors including utilization of proper cutting tool geometry, cutting tool material and the type of coating used to improve hardness and resistance to wear, and also cutting parameters. With the availability of a large array of tool geometries, materials and coatings, is has become a challenging task to select the best tool and cutting parameters that would result in the lowest machining cost or highest profit rate.

Azlan Abdul Rahman et al. [9] presented the effect of drilling parameter such as spindle speed, feed rate and drilling tool size on material removal rate (MRR), surface roughness, dimensional accuracy and burr. In this work, a study on optimum drilling parameter for HSS drilling tool in micro-drilling processes in order to find the best drilling parameter for brass as a work piece material. Micro drilling experiment with 0.5 mm to 1.0 mm drill sizes were performed by changing the spindle speed and feed at three different levels. The results were analyzed using microscope and surface roughness device. Comparatives analysis has been done between surface roughness, MRR and accuracy of drilled holes by experimentation. From the result, the surface roughness are mostly influenced by spindle speed and feed rate. As the spindle and feed rate increases, the surface roughness will decrease.

J. Pradeep Kumar et al.[10] utilized taguchi method to investigate the effects of drilling parameters such as cutting speed (5, 6.5, 8 m/min), feed (0.15, 0.20, 0.25mm/rev) and drill tool diameter (10, 12, 15mm) on surface roughness, tool wear by weight, material removal rate and hole diameter error in drilling of OHNS material using HSS spiral drill. Orthogonal arrays of taguchi, the Signal–to- Noise (S/N) ratio, the analysis of variance (ANOVA), and regression analysis are employed to analyze the effect of drilling parameters on the quality of drilled holes. A series of experiments based on L 18 orthogonal array are conducted using DECKEL MAHO-DMC 835V machining center .The experimental results are collected and analyzed using commercial software package MINITAB 15.

C. C. Tsao et al. [11] analyzed the Taguchi method for drilling quality associates with core drill. The thrust force and surface roughness of core drill with drill parameters (grit size of diamond, thickness, feed rate and spindle speed) in drilling Carbon Fiber Reinforcement Plastic (CFRP) laminates was experimentally investigated. Composite material for drilling was fabricated using autoclave molding. A L27 (313) orthogonal array and signal-to-noise (S/N) were employed to analyze the effect of drill parameters.

S. Basavarajappa et al.[12] discussed the influence of cutting parameters (cutting speed and feedrate) on drilling characteristicsof hybrid metal matrix composite (MMCs). Taguchi design of experiments and analysis of variance (ANOVA) are employed to analyze the drilling characteristics of these composites. The experiments were conducted to study the effect of spindle speed and feed rates on feed force, surface finish and burr height using solid carbide multi facet drills of 5 mm diameter. The result shows that the dependent variables are greatly influenced by the feed rate rather than the speed for the both composites. The ceramic-graphite reinforced composite has better machinability than those reinforced with SiCp composite.

CHAPTER-III

DESIGN OF EXPERIMENTS

3.0 Introduction to Design of Experiments

Design of Experiment is an experimental or analytical method that is commonly used to statistically signify the relationship between input parameters to output responses. DOE has wide applications especially in the field of science and engineering for the purpose of process optimization and development, process management and validation tests. DOE is essentially an experimental based modeling and is a designed experimental approach which is far superior to unplanned approach whereby a systematic way will be used to plan the experiment, collect the data and analyze the data. A mathematical model has been developed by using analysis techniques such as ANOVA and regression analysis whereby the mathematical model shows the relationship between the input parameters and the output responses. Among the most prominently used DOE techniques are Response Surface Methodology with Central Composite Design, Taguchi's method and Factorial Design. In DOE, synergy between mathematical and statistical techniques such as Regression, Analysis of Variance (ANOVA), Non-Linear Optimization and Desirability functions helps to optimize the quality characteristics considered in a DOE under a cost effective process. ANOVA helps to identify each factor effect versus the objective function.

Experimental design was first introduced in the 1920s by R. A. Fischer working at the agricultural field station at Rothamsted in England. Fischer concerned with arranging trials of fertilizers on plots to protect against the underlying effect of moisture, gradient, nature of soils, etc. Fischer developed the basic principles of factorial design and the associated data analysis known as ANOVA during research in improving the yield of agricultural crops.

3.1 Advantages & Disadvantages of DOE

DOE became a more widely used modeling technique superseding its predecessor one-factor-at- time (OFAT) technique. One of the main advantages of DOE is that it shows the relationship between parameters and responses. In other words, DOE shows the interaction between variables which in turn allows us to focus on controlling important parameters to obtain the best responses. DOE also can provide us with the most optimal setting of parametric values to find the best possible output characteristics. Besides from that, the mathematical model generated can be used as a prediction model which can predict the possible output response based on the input values. Another main reason DOE is used because it saves time and cost in terms of experimentation. DOE function in such manner that the number of experiments or the number of runs is determined before the actual experimentation is done. This way, time and cost can be saved as we do not have to repeat unnecessary experiment runs. Most usually, experiments will have error occurring. Some of them might be predictable while some errors are just out of control. DOE allows us to handle these errors while still continuing with the analysis. DOE is excellent when it comes to prediction linear behavior. However, when it comes to nonlinear behavior, DOE does not always give the best results.

3.2 Methodology

For conducting trial runs values or levels of these variables were chosen randomly from an infinite potential level i.e. the sampling fraction for these trials runs was equal to zero, however, we got a rough range of these factors from the literature we surveyed. With the help of these trials runs effective, representative's levels were developed for each factor (variables).

Three factor, three level Response Surface Method (RSM) Design is used to perform the machining operations. Total 20 combinations of experiments are performed. The levels for each factor were the highest value and the lowest value of the factors in between and at which the outcome was acceptable. These values were outcomes of trials runs. Highest value has been represented by '+'and the lowest value has been represented by '-' as mentioned in

Table 3.1. As per the design matrix the final runs were conducted and the response

Table 3.1 Typical design matrix

Experiment No.	Factor A	Factor B	Factor C
1	-1	-1	-1
2	+1	-1	-1
3	-1	+1	-1
4	+1	+1	-1
5	-1	-1	+1
6	+1	-1	+1
7	-1	+1	+1
8	+1	+1	+1
9	-1	0	0
10	+1	0	0
11	0	-1	0
12	0	+1	0
13	0	0	-1
14	0	0	+1
15	0	0	0
16	0	0	0
17	0	0	0
18	0	0	0
19	0	0	0
20	0	0	0

3.3 Development of Mathematical Models

A low-order polynomial is employed for developing the mathematical model for predicting output responses. If the response is well modeled by a linear function of the independent variables then the approximating function is the first order model as shown in Equation 1.

$$Y = \beta + \beta_1 x_1 + \beta_2 x_2 + \ldots\_ \beta_x x_x + \in \qquad \text{Eq-(3.1)}$$

3.4 Estimated of Regression Coefficients

The regression coefficient of the model were computed using the following formula based on the method of least squares.

$Bj=x_{ji}y_i$
N
Where:
$J = 0, 1, 2\ldots k$
N = Number of experimental trails
X = Number of columns of the designed matrix
$x\mu$= value of a factor or interaction in coded form.
Yl=Average

A matrix designed to apply the above formula for the calculation of regression co-efficient of the model is given in table. Because of the orthogonal property of the design, the estimated coefficients are uncorrelated with one another. Since the method of least squares has been used, the estimates also possess the property of minimum variance. All the regression coefficients of the model is expressed by the above equation were estimated for the response parameter i.e. surface and material removal rate.

Checking the Adequacies of the Models

All the above estimated coefficients were used to construct the models for the response parameter and these models were used to construct the models for the response parameter and these models were tested by applying Analysis Of Variance (ANOVA) technique F-ratio was calculated and compared, with the standard values for 95% confidence level. If the calculated value is less than the F-table values the model is consider adequate.

In the present case the tabulated value of F-ratio was found out as follows.

$F_{ratio} = 2 \times (S^2_{ad} / S^2_y)$

Where.

S^2_{ad} = Variance of adequacy or residual variance

S^2y = Variance of optimization parameter of variance of reproducibility.

The variance of adequacy was calculated by $S^2_{ad} = 2 (y_{avg} - y_{pre})^2 / DOF$

Where y_{avg} = Value of response predicted.

DOF = Degree of freedom and is equal to (n-(K+1)

N = No of experimental trials

K = No. of independent variables

$S^2_y = 2 (y_1 - y_{avg})^2 / DOF$

Y_{avg} = average of response observed

Y_1 = other of the values of response parameter

DOF = Degree of freedom is equal to the number of experimental runs

3.6 Standard Fisher Ratio Table

A ratio has been developed in statistics that is very convenient for testing a hypothesis on the adequacy of the model.

The convenience of using the F-ratio consists in that the testing of hypothesis can be reduced to compare N tabulated value.

The table constructed as follows.

The columns are related to a definite number of degrees of freedom for the number f1 and rows for the denominator f2. The critical values of the F-ratio are found at the intersection of the corresponding rows and columns. As a role, a significance level of 5% (confidence level of 95%) is used in technical problems. (F- Table shown in Table 3.2).

3.7 Development of the Final Mathematical Model

The final mathematical model was constructed by using only significant coefficients and are shown in table.

The values predicted by these model were also checked by actually conducting experiments by keeping the value of the process parameter at some values other than those used for developing the models but within the zone and the results obtained were found satisfactory. Then these models were used for drawing graphs and analyzing the results.

Table 3.2 Values of F- Ratio at 95% significance Level

	1	2	3	4	5	6	12	24	00
1	164.4	199.5	215.7	224.6	230.2	234.0	244.9	249.0	254.3
2	18.5	19.2	19.3	19.3	19.3	19.4	19.4	19.4	19.5
3	10.1	9.6	9.3	9.1	9.0	8.9	8.7	8.7	8.5
4	7.7	6.9	6.6	6.4	6.3	6.2	5.9	5.8	5.6
5	6.6	5.8	5.4	5.2	5.1	5.0	4.7	4.5	4.4
6	6.0	5.1	4.8	4.5	4.4	4.3	4.0	3.8	3.7
7	5.5	4.7	4.4	4.1	4.0	3.9	3.6	3.4	3.2
8	5.3	4.5	4.1	3.8	3.7	3.6	3.3	3.1	2.0
9	5.1	4.3	3.9	3.6	3.5	3.2	2.9	2.7	2.5
10	5.0	4.1	3.7	3.5	3.3	3.2	2.9	2.7	2.5
11	4.8	4.0	3.6	3.4	3.2	3.0	2.9	2.5	2.3
12	4.8	3.9	3.5	3.3	3.1	3.0	2.7	2.5	2.3
13	4.7	3.8	3.4	3.2	3.0	2.9	2.6	2.4	2.2
14	4.6	3.7	3.3	3.1	3.0	2.9	2.5	2.3	2.1
15	4.5	3.7	3.3	3.1	2.0	2.8	2.5	2.3	2.1
16	4.5	3.6	3.2	3.0	2.9	2.7	2.4	2.2	2.0
17	4.5	3.6	3.2	2.9	2.8	2.7	2.4	2.2	2.0
18	4.4	3.6	3.2	2.9	2.8	2.7	2.3	2.1	1.9
19	4.4	3.5	3.1	2.9	2.7	2.6	2.3	2.1	1.9
20	4.4	3.5	3.1	2.9	2.7	2.6	2.3	2.1	1.8
22	4.3	3.4	3.1	2.8	2.7	2.6	2.2	2.0	1.8
24	4.3	3.4	3.0	2.8	2.6	2.5	2.2	2.0	1.7
26	4.2	3.4	3.0	2.7	2.6	2.5	2.2	2.0	1.7
28	4.2	3.3	3.0	2.7	2.6	2.4	2.1	1.0	1.7
30	4.2	3.3	2.9	2.7	2.5	2.4	2.1	1.9	1.6
40	4.1	3.2	2.9	2.6	2.5	2.3	2.0	1.8	1.5
60	4.0	3.2	2.8	2.5	2.4	2.3	1.9	1.7	1.4
120	3.9	3.1	2.7	2.5	2.3	2.2	1.8	1.6	1.3
00	3.8	3.0	2.6	2.4	2.2	2.1	1.8	1.5	1.0

CHAPTER – IV

EXPERIMENTAL SETUP

In this chapter,we discuss about the experimental setup and its specifications.Work piece and Drill bits are also shown.

4.1 Introduction of Radial Drilling Machine

Radial drilling machines are designed to offer rigidity, precision and ease in operation. Some of these machines are built to withstand static as well as sever dynamic loads. These machines have a higher work piece capacity than uprights. Various types of radial machines like standard, horizontal spindle and universal radial drilling machines are available in the market.

Standard drillers are the most widely used and they are designed for the spindle to stay in a vertical position at all times (Figure 4.1). Horizontal-spindle work on larger work pieces requiring horizontal drilling, universal drilling machines have no base but instead they have a runway where the column and the column base can be traversed.

The radial drilling machines are used in small and big workshops, engineering industries, dies, tools and mould manufacturing, machine tool builders, automobile and ship-building industries, railway, defense, fabrications shops etc.

Fig 4.1 Radial Drilling Machine

4.2 Radial Drilling Machine Specifications:

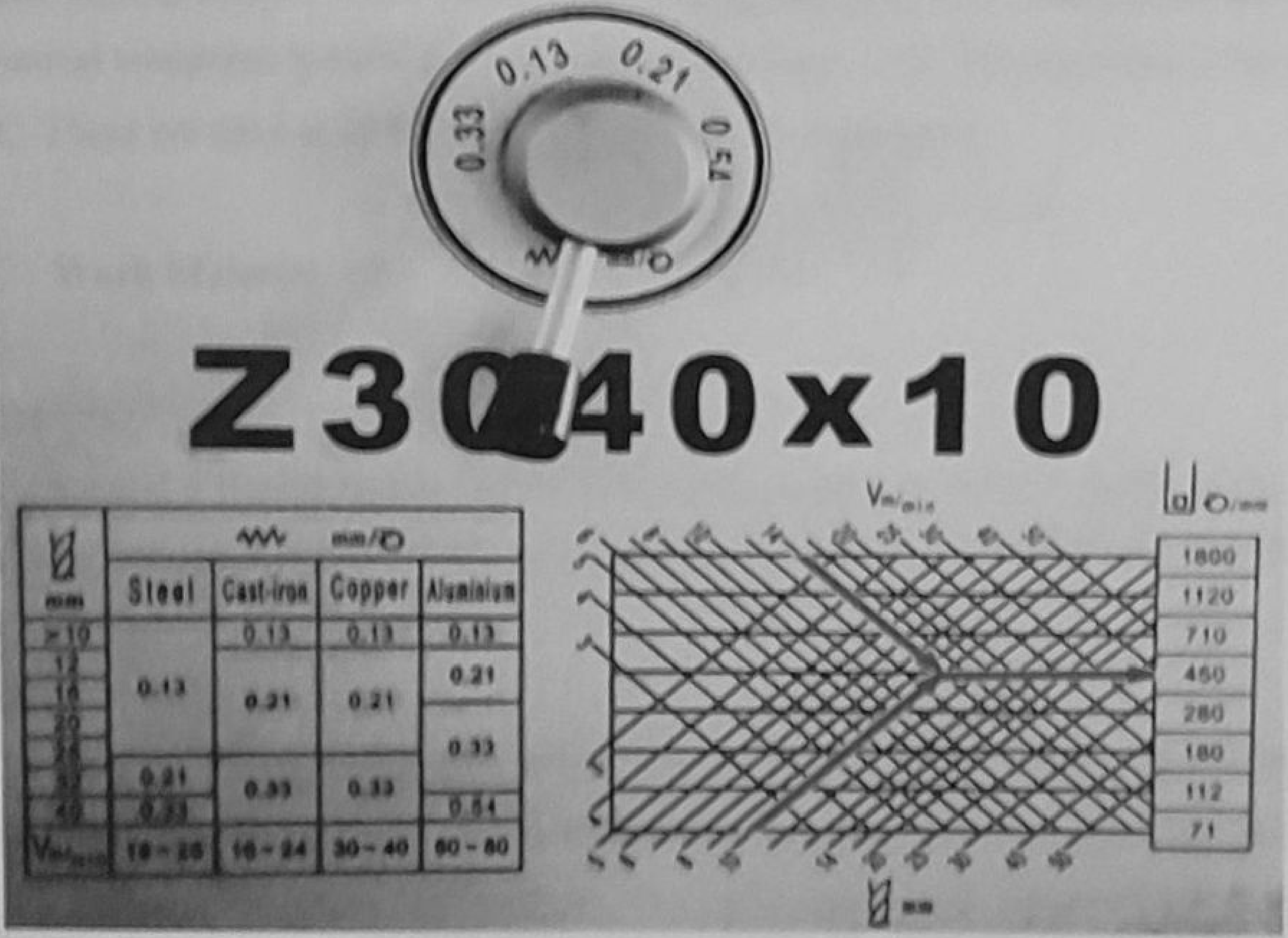
Drilling Capacity: 400mm

Radius: 1125mm

Number of speeds: 8

Speed Range: 71 - 1800 rpm

Power: 3HP



mm	Steel	Cast-iron	Copper	Aluminium
>10	0.13	0.13	0.13	0.13
12		0.21	0.21	0.21
16				
20				0.33
25				
32	0.21	0.33	0.33	
40	0.33			0.54
Vm/min	18 - 25	16 - 24	30 - 40	60 - 80

Fig 4.2 Specifications of radial drilling machine for various metals

4.3 Tool Material

High Speed Tool Steel

High speed steels (HSS) are carbon steels with alloying elements such as Tungsten (W), Chromium (Cr), Vanadium (V), Molybdenum (Mo) and Cobalt (Co).

These are normally grouped into three classes:

Class – I: 18-4-1 HSS: 18% W, 4% Cr, 1%V.

This type is called Tungsten type HSS and is well known for air and heat resistance. **Class – II**: 6-6-4-2: 6%W, 6%Mo, 4%Cr, 2%V. This type is called Molybdenum type HSS and is well known for wear and impact resistance.

Class – III: Super HSS: 2 to 15% Co additionally to increase cutting efficiency for heavier cut imparting higher temperatures.

The HSS is a tough and heat treatable material with high 'red hardness' retains the cutting edge up to 650^0C. The High speed steels find application s as single point tools, drills, reamers, milling cutters. These can be sharpened by grinding with Aluminum oxide which, economical compared to carbide tools and perform fairly well. The hardness is about 65 to 67 RC. These are used at 20 to 30 surface in / min for most steels.

4.4 Work Material

Bronze

Several different metals can be mixed with copper to make a useful alloy. Tin has been the most commonly used alloying element, but arsenic, antimony and lead have also been used.

Bronze with 11% tin, 50x magnification Bronze is a mixture of elements, not a compound, so in theory any proportions can be made. Bronze is harder than copper, making it useful for tools and weapons. It can be sharpened. Bronze melts at a lower temperature than pure copper. It also flows better into molds. Since it is less likely that bubbles will be trapped, the cast bronze object will be harder than cast copper. The microscopic structure of bronze explains some of the observed properties. Small amounts of tin can be incorporated into a copper lattice as substitutional impurities. Since tin atoms are larger than copper atoms, it is hard for planes of atoms to slip past them. This reduces the flexibility of the metal. Large amounts of tin in a sample will create precipitates, having a crystal structure distinct from that of the main lattice. This type of discontinuity also makes it hard for planes of atoms to slip. 10% tin in copper is a popular ratio that results in excellent properties. Due to the inhomogeneous crystal lattice, bronze alloys have lower electrical conductivity than pure copper. Bronze was the most important material in the world but was eventually superseded by iron, which was more common but more difficult to work with. Historians have theorized that the Bronze Age ended because tin supplies became scarce.

Bronze is a tin alloy of copper which is harder than either of the alloy metal ingredients. It is extremely strong and resistant to atmospheric corrosion. It has been used since prehistoric times to forge tools, weapons, statues and ornaments. It has a comparatively low melting point, which metalworkers in ancient times could achieve with charcoal and bellows. This allowed them to cast complex shapes. Other metals such as lead, gold or silver were sometimes added to alter the color, improve the finish or make the molten bronze flow better.

Ancient bronze was usually made up of copper, tin and small amounts of noble metals or lead. The amount of tin could reach 40 percent but classic bronze alloy and today's commercial bronze are 10 percent tin and 90 percent copper. Alloys with more tin are technically brass alloys. Manganese is added to bronze used for ships' propellers because it resists saltwater corrosion. Iron, nickel, silicon and aluminum are added for strength in tools because bronze will not make a spark when struck.Bronze strength depends on the composition of the alloy and ranges from 35,000 pounds per square inch (psi) tensile strength for standard bronze through 85,000 psi for aluminium bronze to 119,000 psi for manganese bronze. The yield strength ranges from 32,000 to 68,000 psi Brinell hardness measures from 65 to 225. Ancient bronze was at the lower end of these figures but modern aluminum and manganese bronzes are used in marine fittings, bearings and pumps where high strength and hardness are required.

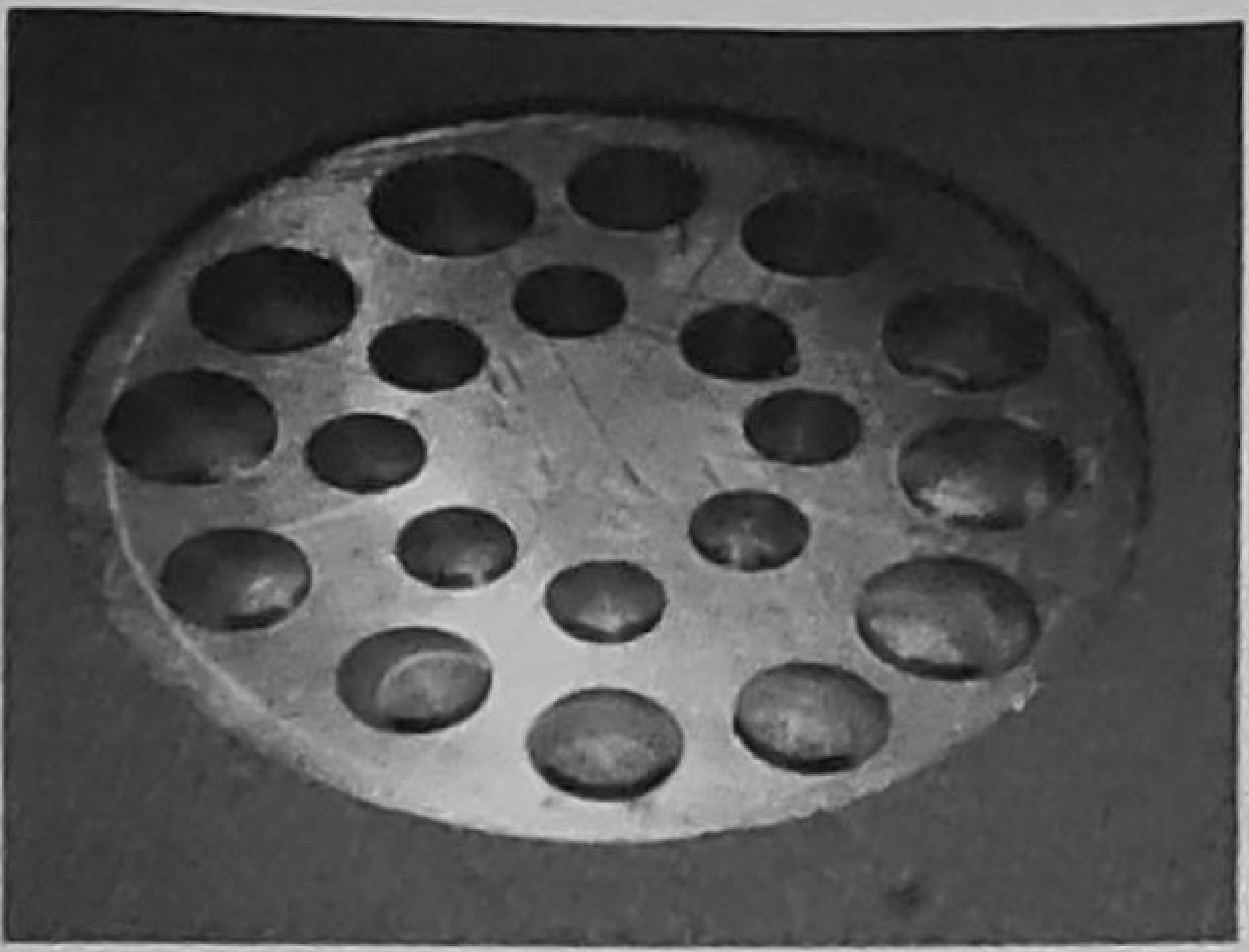


Fig 4.3 Work piece material

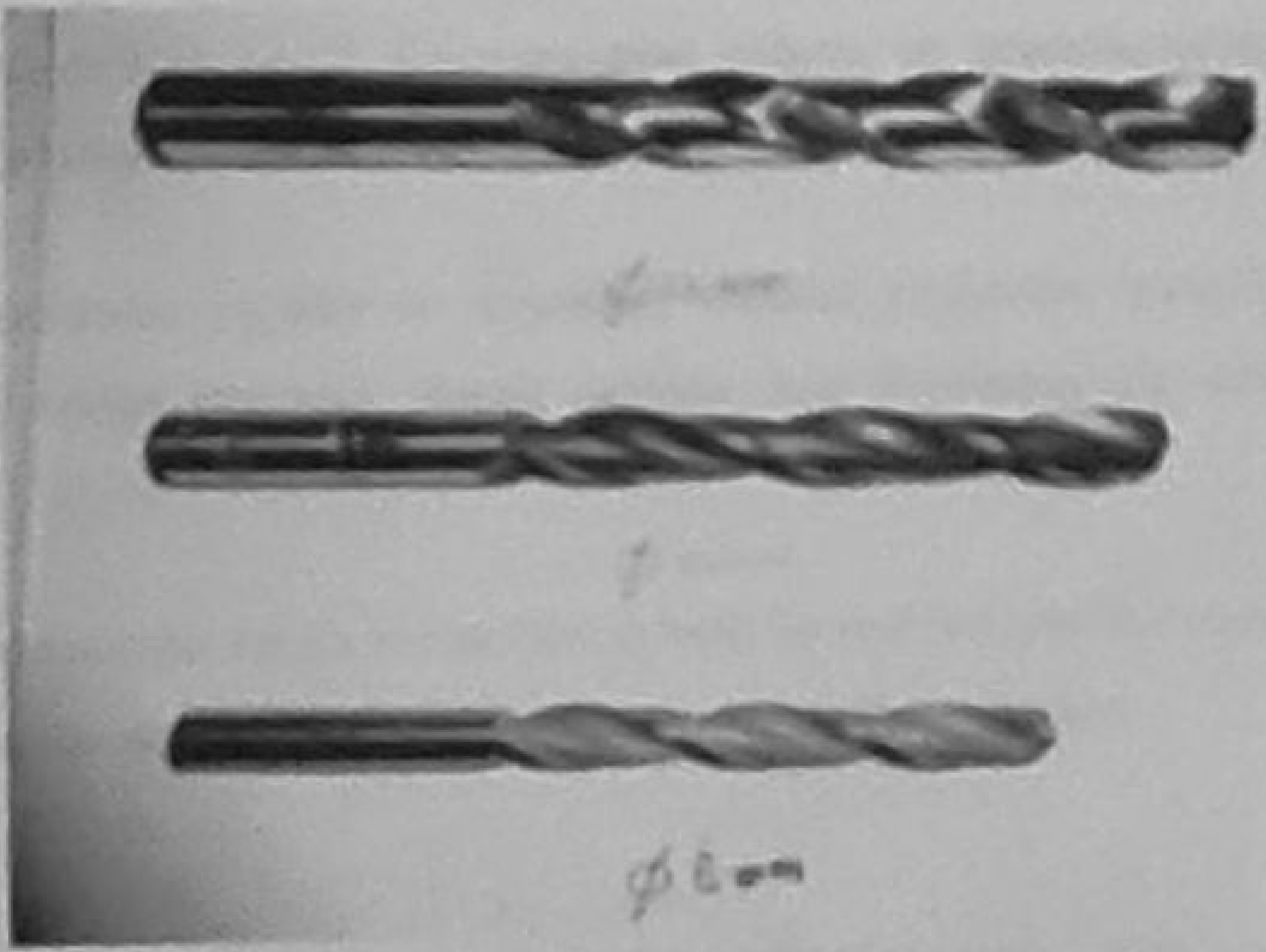


Fig 4.4 Various drill bits used for machining

4.5 Coordinate Measuring Machine (CMM)

With the advent of numerically controlled machine tools, the demand has grown for some means to support these equipment. There has been growing need to have an apparatus that can do faster first piece inspection and many times, 100% dimensional inspection. The Coordinate Measuring Machine (CMM) plays a vital role in the mechanization of the inspection process. Some of the CMMs can even be used as layout machines before machining and for checking feature locations after machining.

Coordinate measuring machines are relatively recent developments in measurement technology. Basically, they consist of a platform on which the workpiece being measured is placed and moved linearly or rotated. A probe attached to a head capable of lateral and vertical movements records all measurements. Coordinate measuring machines are also called measuring machines. They are versatile in their capability to record measurement of complex profiles with high sensitivity ($0.25\ \mu m$) and speed.

Co-ordinate Measuring Machines are built rigidly and are very precise. They are equipped with digital readout or can be linked to computers for online inspection of parts. These machines can be placed close to machine tools for efficient inspection and rapid feedback for correction of processing parameter before the next part is made. They are also made more rugged to resist environmental effects in manufacturing plants such as temperature variations, vibration and dirt. Important features of the CMMs are:

(i)To give maximum rigidity to machines without excessive weight, all the moving members, the bridge structure, *Z*-axis carriage, and *Z*-column are made of hollow box construction.

(ii)A map of systematic errors in machine is built up and fed into the computer System so that the error compensation is built up into the software.

(iii)All machines are provided with their own computers with interactive dialogue facility and friendly software.

(iv)Thermocouples are incorporated throughout the machine and interfaced with the computer to be used for compensation of temperature gradients and thus provide increased accuracy and repeatability.

A CMM consists of four main elements:

Main Structure

The machine incorporates the basic concept of three coordinate axes so that precise movement in x, y, and z directions is possible. Each axis is fitted with a linear measurement transducer. The transducers sense the direction of movement and gives digital display. Accordingly, there may be four types of arrangement:

Cantilever

The cantilever construction combines easy access and relatively small floor space requirements. It is typically limited to small and medium sized machines. Parts larger than the machine table can be inserted into the open side without inhibiting full machine travel.

Bridge Type

The bridge arrangement over the table carries the quill (z-axis) along the x-axis and is sometimes referred to as a travelling bridge. It is claimed that the bridge construction provides better accuracy, although it may be offset by difficulty in making two members track in perfect alignment. This is by far the most popular CMM construction. Figure 4.5shows a bridge structure.

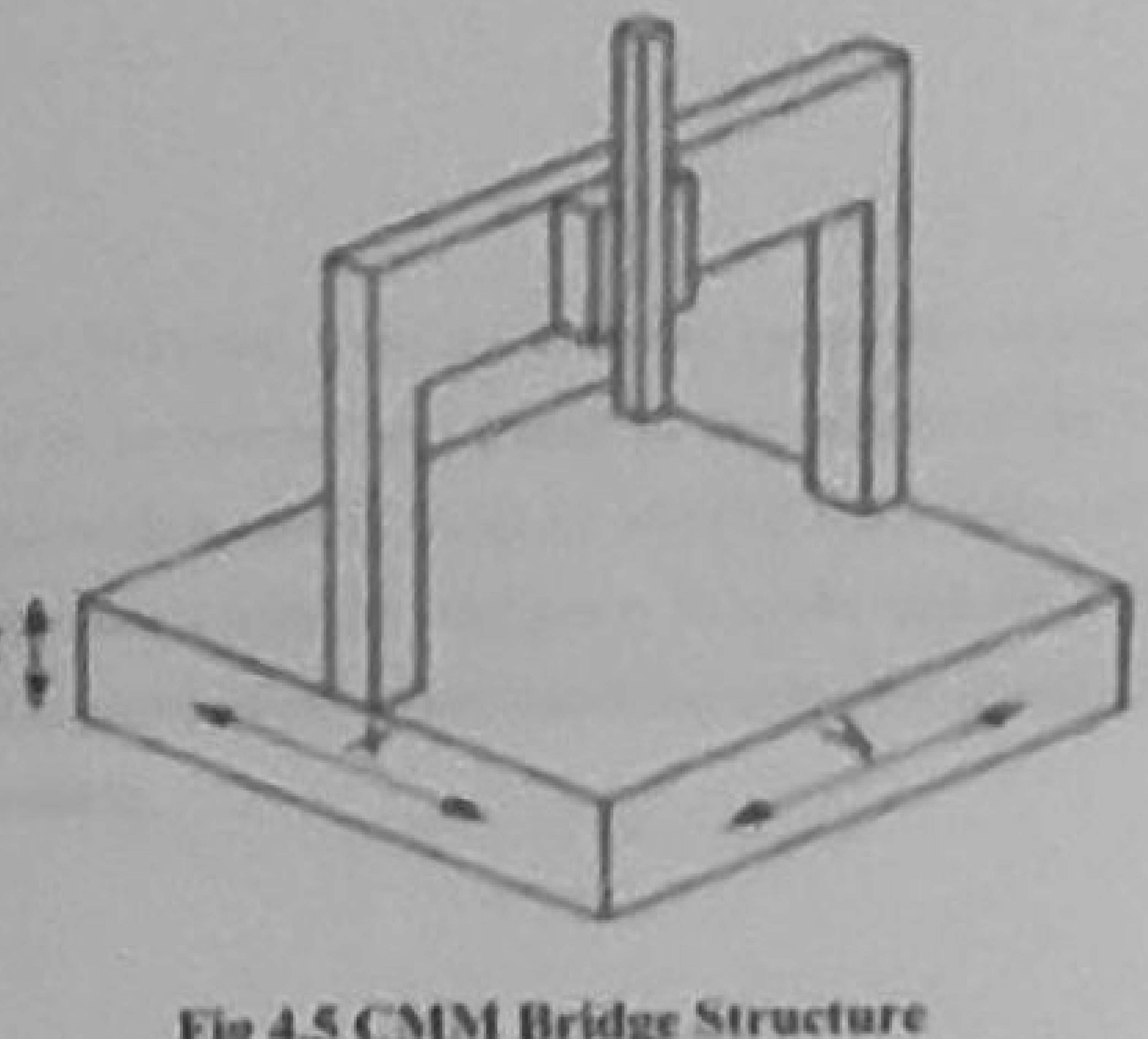


Fig 4.5 CMM Bridge Structure

Column Type

The column type machine is commonly referred to as a universal measuring machine rather than a CMM. These machines are usually considered gage room instruments rather than production floor machine. The direction of movements of the arms are can be shown. The constructional difference in column type with the cantilever type is with x and y-axes movements.

Gantry

In a gantry type arrangement, arms are held by two fixed supports. Other two arms are capable of sliding over the supports. Movements of the x, y and z-axes are also can be shown. The gantry type construction is particularly suited for very large components and allows the operator to remain close to the area of inspection

Horizontal

Figures shows the construction of a horizontal structure. The open structure of this arrangement provides optimum accessibility for large objects such as dies, models, and car bodies. Some horizontal arm machines are referred to as layout machines. There are some horizontal machines where the probe arm can rotate like a spindle to perform tramming operations. Tramming refers to accurate mechanical adjustment of instrument or machine with the help of tram.

Probe system

It is the part of a CMM that sense the different parameters required for the calculation. Appropriate probes have to be selected and placed in the spindle of the CMM. Originally, the probes were solid or hard, such as tapered plugs for locating holes. These probes required manual manipulation to establish contact with the workpiece, at which time the digital display was read. Nowadays, transmission trigger-probes, optical transmission probes, multiple or cluster probes, and motorized probes are available.

Fig 4.6 Co-ordinate Measuring Machine

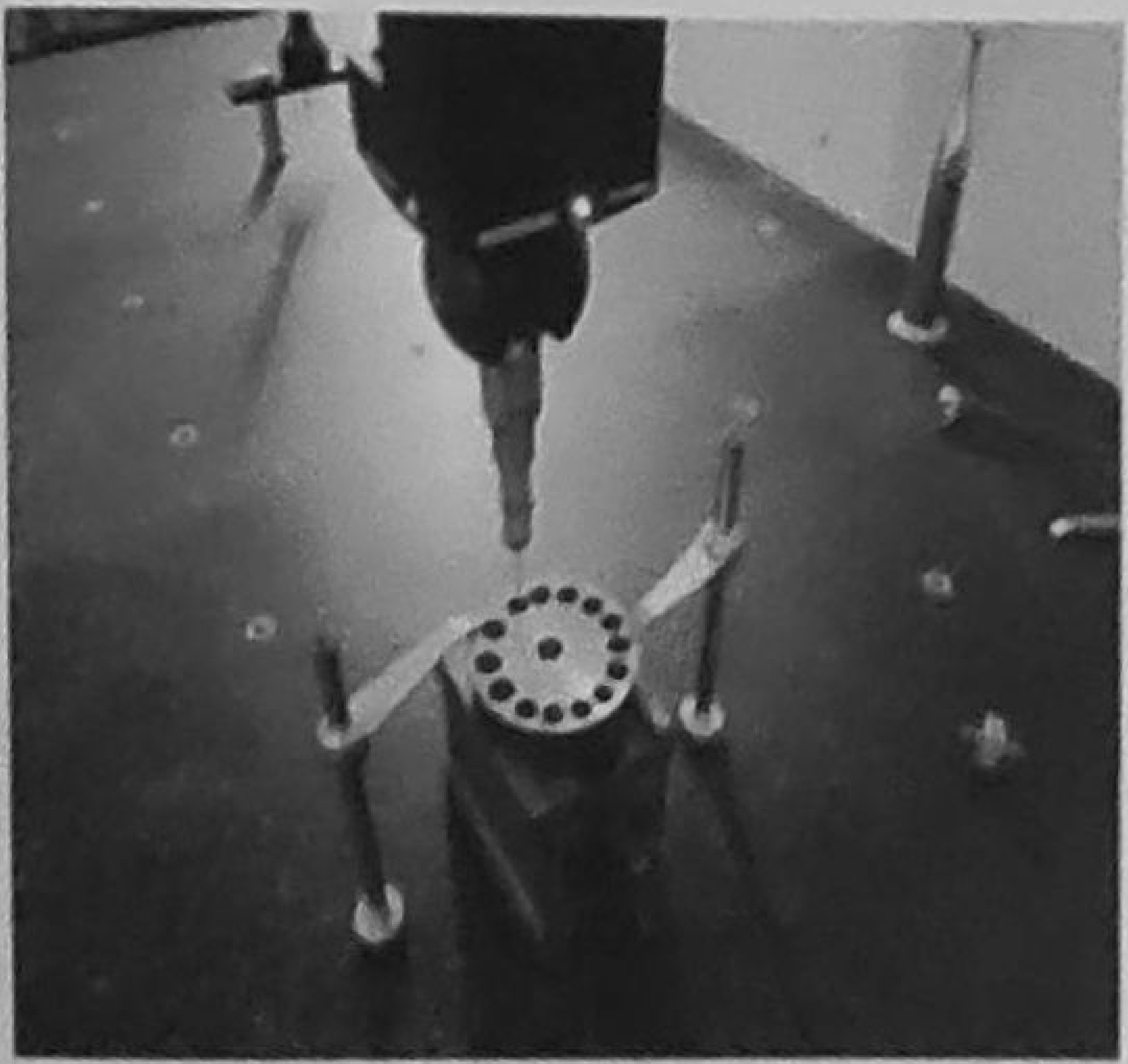
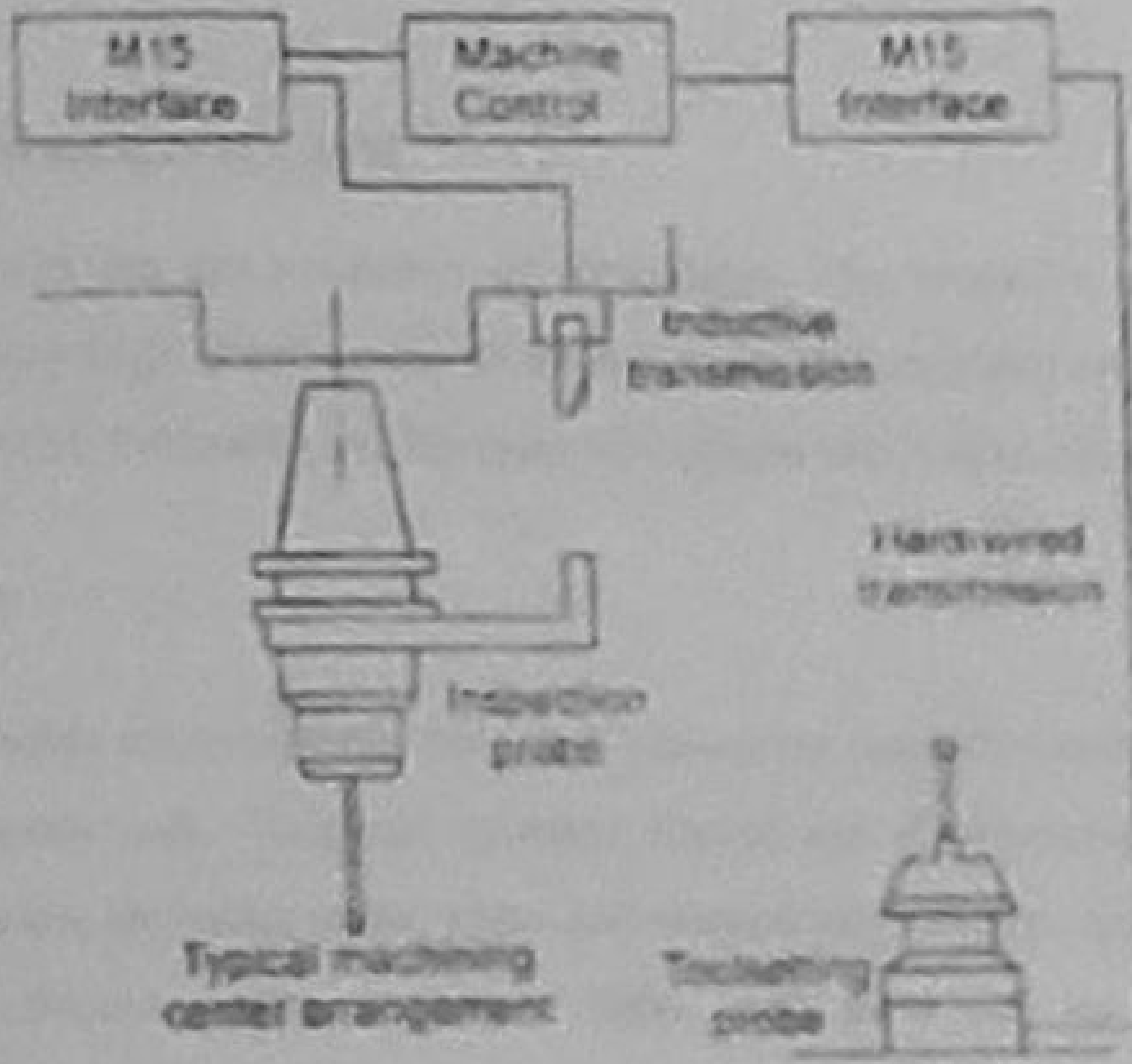


Fig 4.7 Probe touching figure



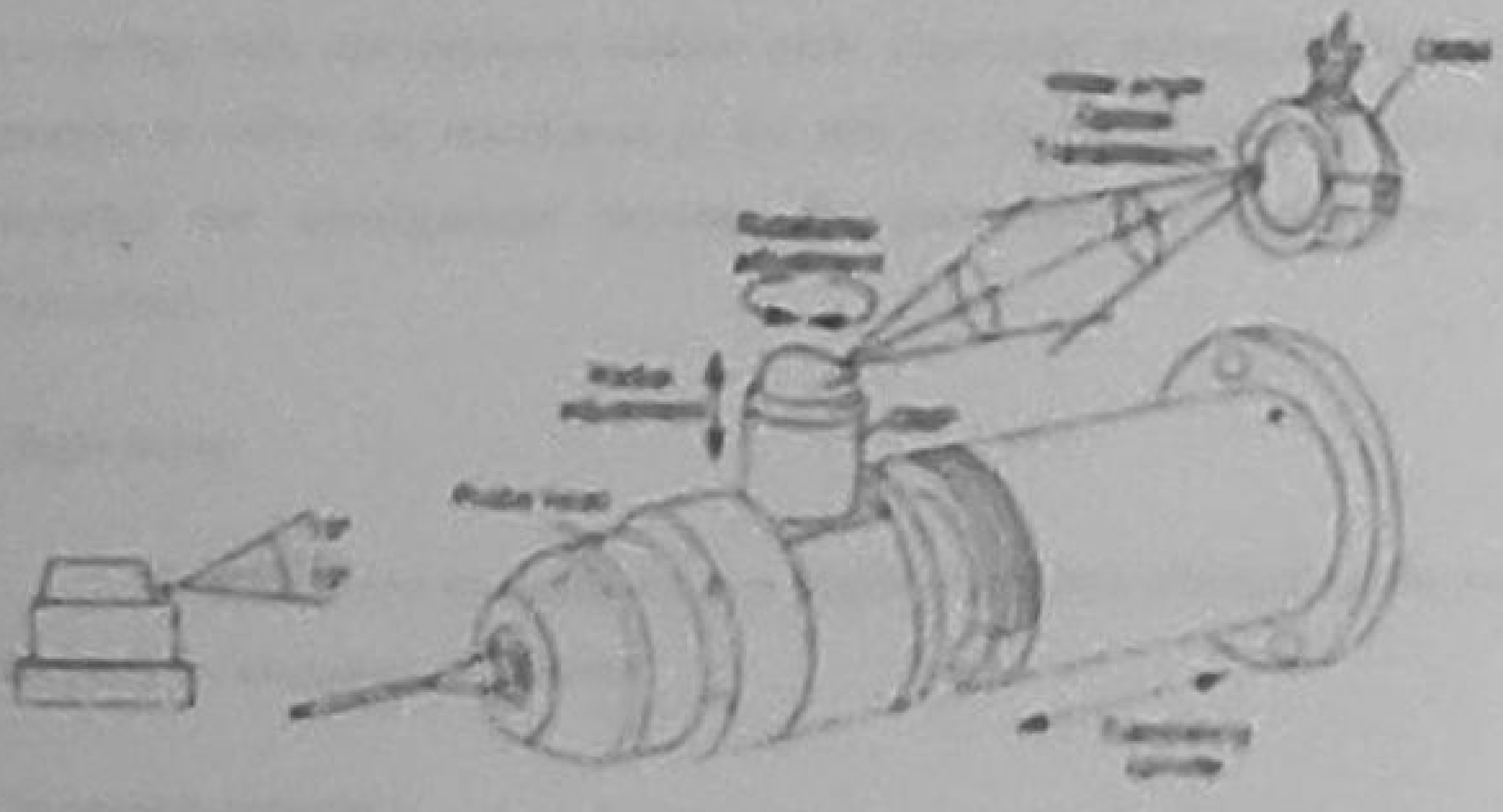


Fig 4.8 Inductive Probe System and Automatic Probe Changing

4.6 Advantages of CMM

CMM has got a number of advantages. The precision and accuracy given by a CMM is very high. It is because of the inherent characteristics of the measuring techniques used in CMM. Following are the main advantages that CMM can offer

Flexibility

CMMs are essentially universal measuring machines and need not be dedicated to any particular task. They can measure almost any dimensional characteristic of a part configuration, including cams, gears and warped surfaces. No special fixtures or gages are required. Because probe contact is light, most parts can be inspected without being clamped to the table.

Reduced Setup Time

Part alignment and establishing appropriate reference points are very time consuming with conventional surface plate inspection techniques. Software allows the operator to define the orientation of the part on the CMM, and all subsequent data are corrected for misalignment between the parts-reference system and the machine coordinates.

Single Setup

Most parts can be inspected in a single setup, thus eliminating the need to reorient the parts for access to all features.

Improved Accuracy

All measurements in a CMM are taken from a common geometrically fixed measuring system, eliminating the introduction and the accumulation of errors that can result with hand-gage inspection methods and transfer techniques.

Reduced Operator Influence

The use of digital readouts eliminate the subjective interpretation of readings common with dial or Vernier type measuring devices. Operator "feel" is virtually eliminated with modern touch-trigger probe systems, and most CMMs have routine measuring procedures for typical part features, such as bores or centre distances. In computer assisted systems, the operator is under the control of a program that eliminates operator choice. In addition, automatic data recording, available on most machines, prevents errors in transcribing readings to the inspection report. This adds up to the fact that less skilled operators can be easily instructed to perform relatively complex inspection procedures.

CHAPTER-V

EXPERIMENTAL PROCEDURE AND ANALYSIS

In this chapter we explain about the experimental values and the predicted values that we obtained.

Commercial bronze of thickness 25 mm is taken and both the sides are faced so that flat surface is obtained. Spindle speed, feed and drill diameter are taken as input process parameters. The values of the process parameters selected for the experimentation are shown in Table 5.1. The minimum and maximum values of the process parameters are chosen based on work piece material and tool material.

Table 5.1 Parameters and their limits

	Levels		
Parameter	**-1**	0	+1
Spindle Speed (rpm)	280	450	710
Feed (mm/sec)	0.13	0.21	0.33
Drill Diameter (mm)	8	10	12

Design of Experiments (DOE) is used to select the design matrix. Experiments are performed as per Response Surface Method, CCD matrix for three factors and three levels. Total 20 combinations of experiments are carried out in dry machining condition. Drill hole geometries (Circularity, Cylindricity, Concentricity_X, Concentricity_Y) are measured using CMM s and reported in Table 5.2 for dry machining. Predicted values are presented in Table 5.3.

Table 5.2 Experimental values

Exp.No.	Spindle Speed (rpm)	Feed (mm/sec)	Diameter (mm)	CIRCULARITY (mm)	CYLINDRICITY (mm)	CONCENTRICITY_X (mm)	CONENTRICITY_Y (mm)
1	280	0.13	8	8.1876	8.1871	-0.0165	-0.0915
2	710	0.13	8	8.3025	8.2852	0.0716	0.1334
3	280	0.33	8	8.2196	8.2317	0.129	0.1845
4	710	0.33	8	8.2328	8.233	0.0955	0.0632
5	280	0.13	12	12.2777	12.2634	0.0904	0.0468
6	710	0.13	12	12.0804	12.0917	0.1287	0.1847
7	280	0.33	12	12.032	12.0386	0.0553	0.1322
8	710	0.33	12	12.0381	12.0388	-0.0893	0.1823
9	280	0.21	10	10.1238	10.1152	0.0943	0.1761
10	710	0.21	10	10.0941	10.1154	-0.0202	0.1611
11	450	0.13	10	10.1352	10.1557	0.0848	0.0513
12	450	0.33	10	10.1021	10.0965	0.0652	0.1388
13	450	0.21	8	8.2545	8.2556	0.0685	0.1518
14	450	0.21	12	12.0487	12.0478	-0.0114	0.1251
15	450	0.21	10	10.1256	10.1355	0.1003	0.1714
16	450	0.21	10	10.1278	10.1218	0.1381	0.1178
17	450	0.21	10	10.1238	10.1152	0.1143	0.1761
18	450	0.21	10	10.0941	10.1154	-0.0122	0.1011
19	450	0.21	10	10.1352	10.1557	0.0848	0.0513
20	450	0.21	10	10.1256	10.1355	0.0011	0.1283

Table 5.3 Predicted values

Exp.No.	Spindle Speed (rpm)	Feed (mm/sec)	Diameter (mm)	CIRCULARITY (mm)	CYLINDRICITY(mm)	CONCENTRICITY_X (mm)	CONCENTRICITY_Y (mm)
1	280	0.13	8	8.2333	8.2294	0.000051	-0.0301
2	710	0.13	8	8.2674	8.2615	0.071331	0.10024
3	280	0.33	8	8.1972	8.207	0.149337	0.171956
4	710	0.33	8	8.2787	8.274	0.079308	0.09411
5	280	0.13	12	12.2176	12.2082	0.098486	0.017951
6	710	0.13	12	12.1008	12.1139	0.096382	0.19811
7	280	0.33	12	12.0647	12.0594	0.043274	0.165887
8	710	0.33	12	11.9954	11.9999	-0.100138	0.137859
9	280	0.21	10	10.1279	10.132	0.061352	0.122406
10	710	0.21	10	10.1056	10.1149	0.039417	0.194381
11	450	0.13	10	10.1643	10.1702	0.09275	0.038499
12	450	0.33	10	10.0886	10.0984	0.08392	0.131188
13	450	0.21	8	8.2204	8.2207	0.048073	0.105194
14	450	0.21	12	12.0983	12.099	0.035697	0.151293
15	450	0.21	10	10.1168	10.1244	0.062186	0.13115
16	450	0.21	10	10.1168	10.1244	0.062186	0.13115
17	450	0.21	10	10.1168	10.1244	0.062186	0.13115
18	450	0.21	10	10.1168	10.1244	0.062186	0.13115
19	450	0.21	10	10.1168	10.1244	0.062186	0.13115
20	450	0.21	10	10.1168	10.1244	0.062186	0.13115

5.1 Development of empirical models

Using MINITAB 14 statistical software package, the significant coefficients were determined and final model is developed using second order polynomial equation to estimate Cylindricity, Circularity, Concentricity_X and Concentricity_Y.

CIRCULARITY =

$$1.04601+0.00039X_1+0.00568X_2+0.49163X_3+0.000001X_1^2-0.00003X_1X_3$$

CYLINDRICITY=

$$0.882061+0.000351X_1+0.132428X_2+0.510492X_3+0.000001X_1^2 -$$
$$0.000026X_1X_3$$
$$-0.055882X_2X_3$$

CONCENTRICITY_X =

$$-1.17068+0.00056X_1+1.16316X_2+0.10185X_3-0.09038X_2X_3$$

CONENTRICITY_Y=

$$-0.66546-0.00003X_1+2.90897X_2+0.01619X_3-0.00086X_1X_2$$

Where X_1,X_2, X_3 are the coded values of Spindle speed, feed and drill diameter.

5.2 Checking the adequacy of the developed models

The adequacy of the developed model was tested using the Analysis of Variance technique (ANOVA). As per this technique, if the calculated value of the F_{ratio} of the developed model is less than the standard F_{ratio} (from F-table) value at a desired level of confidence (say 95%), then the model is said to be adequate within the confidence limit. ANOVA results are presented in Table 5.4, 5.5, 5.6 & 5.7.

Table 5.4 Analysis of Variance for CIRCULARITY

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	37.2168	37.216798	4.135200	2194.76	0.000
Linear	3	37.1818	0.093917	0.031306	16.62	0.000
Square	3	0.0153	0.015407	0.005136	2.73	0.100
Interaction	3	0:0196	0.019648	0.006549	3.48	0.058
Residual Error	10	0.0188	0.018841	0.001884		
Lack-of-Fit	5	0.0178	0.017826	0.003565	17.57	0.003
Pure Error	5	0.0010	0.001015	0.000203		
Total	19	37.2356				

Table 5.5 Analysis of Variance for CYLINDRICITY

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	37.2395	37.239544	4.137727	2610.13	0.000
Linear	3	37.2113	0.101012	0.033671	21.24	0.000
Square	3	0.0113	0.011379	0.003793	2.39	0.129
Interaction	3	0.0169	0.016873	0.005624	3.55	0.056
Residual Error	10	0.0159	0.015853	0.001585		
Lack-of-Fit	5	0.0146	0.014632	0.002926	11.99	0.008
Pure Error	5	0.0012	0.001220	0.000244		
Total	19	37.2554				

Table 5.6 Analysis of Variance for CONCENTRICITY_X

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	0.043599	0.043599	0.004844	1.63	0.228
Linear	3	0.006970	0.017072	0.005691	1.92	0.191
Square	3	0.002558	0.002478	0.000826	0.28	0.840
Interaction	3	0.034071	0.034071	0.011357	3.82	0.046
Residual Error	10	0.029711	0.029711	0.002971		
Lack-of-Fit	5	0.010485	0.010485	0.002097	0.55	0.739
Pure Error	5	0.019227	0.019227	0.003845		
Total	19	0.073310				

Table 5.7 Analysis of Variance for CONENTRICITY_Y

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	0.05947	0.05947	0.006608	2.34	0.101
Linear	3	0.02384	0.02255	0.007516	2.66	0.105
Square	3	0.01089	0.01125	0.003751	1.33	0.320
Interaction	3	0.02474	0.02474	0.008247	2.92	0.087
Residual Error	10	0.02828	0.02828	0.002828		
Lack-of-Fit	5	0.01745	0.01745	0.003491	1.61	0.307
Pure Error	5	0.01083	0.01083	0.002166		
Total	19	0.08775				

5.3 Main Effect of process parameters on Circularity

The effect of input parameters on circularity ispresented in Figure 5.1.There is no much effect of spindle speed and feed on hole circularity. However, as drill diameter increases circularity also increases.

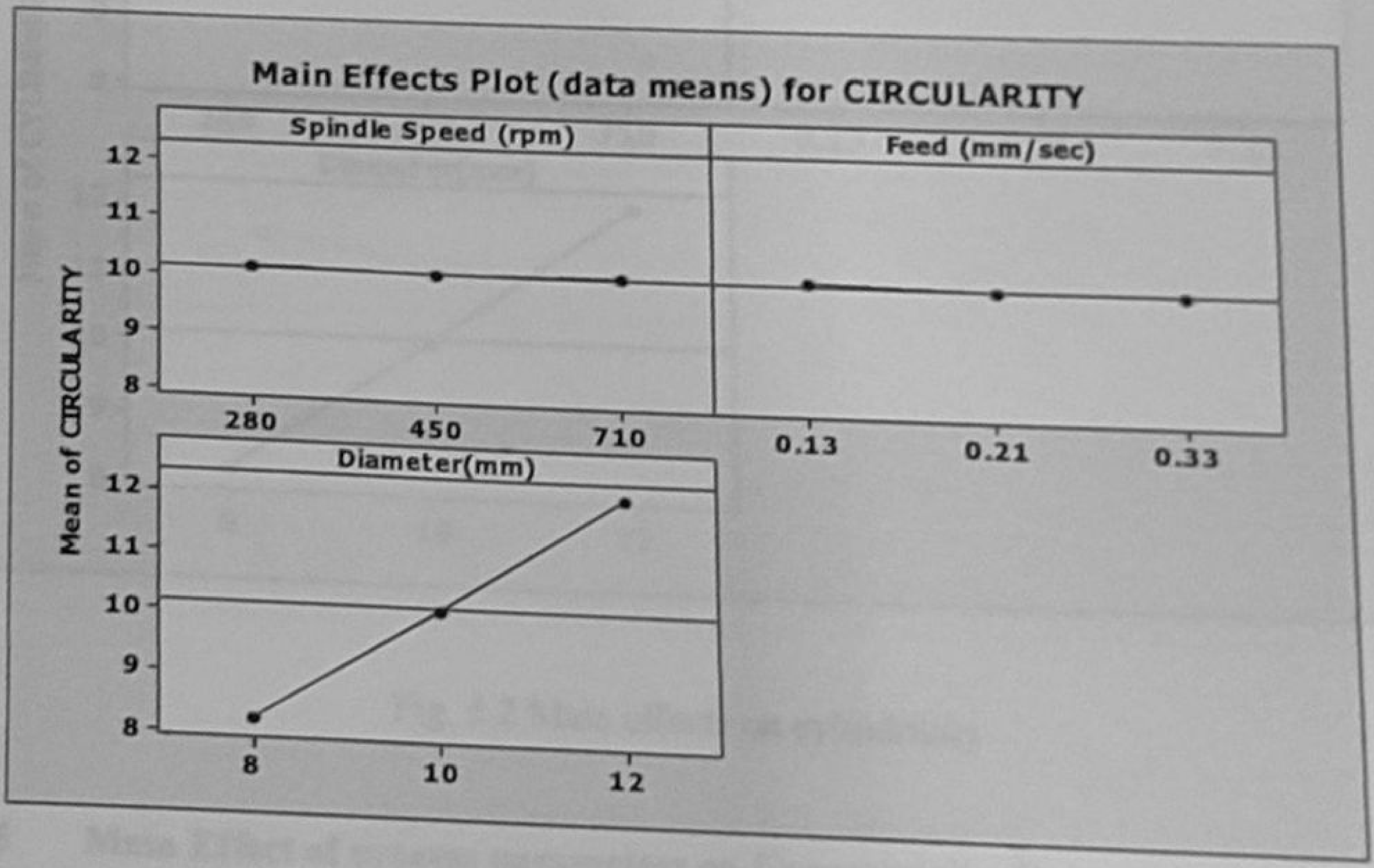


Fig. 5.1 Main effects on circularity

5.4 Main Effect of process parameters on Cylindricity

The effect of input parameters on Tool Wear'spresented in Figure 5.2. There is no much effect of spindle speed and feed on hole circularity. However, as drill diameter increases circularity also increases.

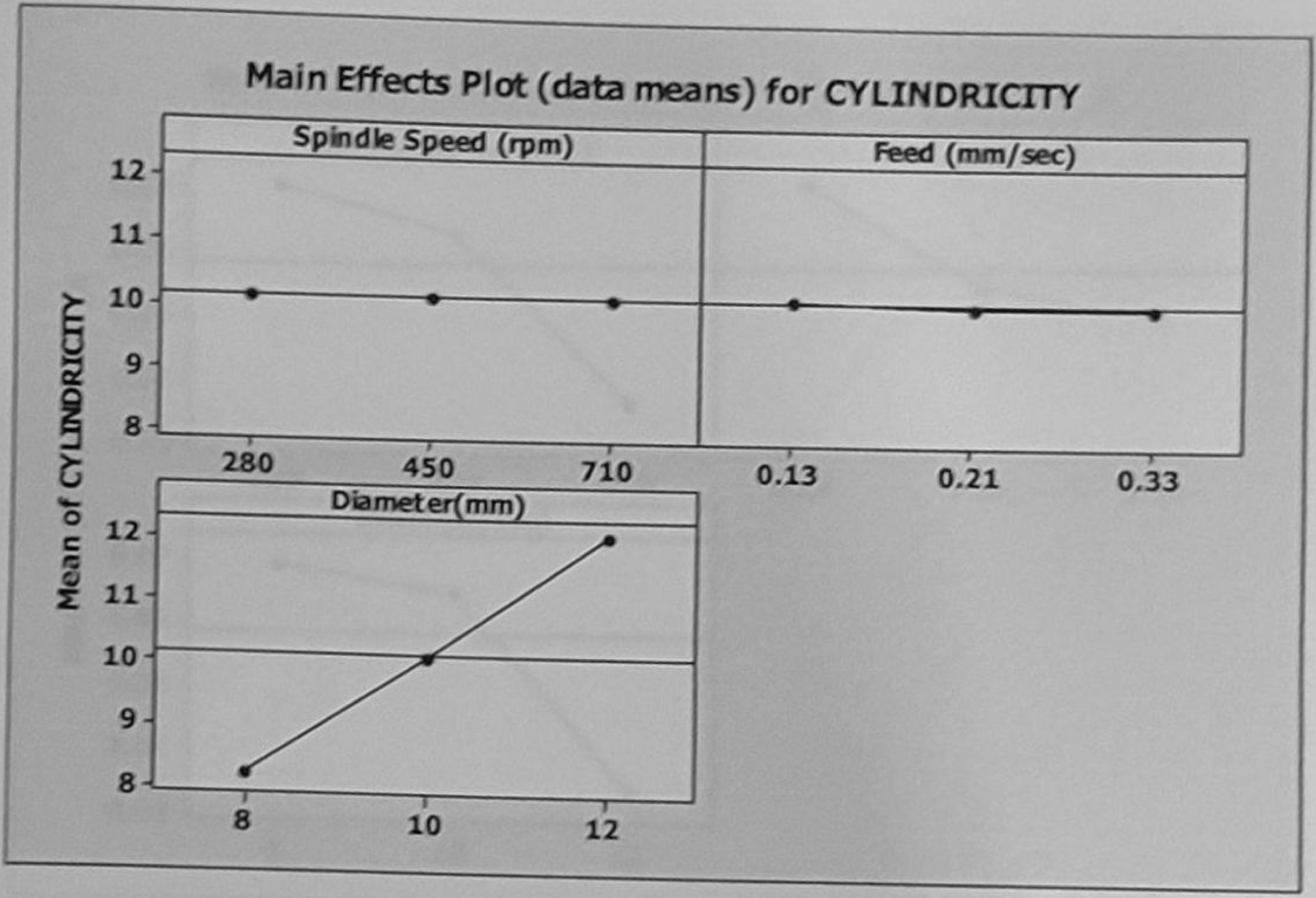


Fig. 5.2 Main effects on cylindricity

5.5 Main Effect of process parameters on Concentricity_X

The effect of input parameters on Concentricity along X-axis is presented in Figure 5.3. All the input parameters have negative effect on the output response. Concentricity along X-axis is deceased with increase in spindle speed, feed and drill diameter.

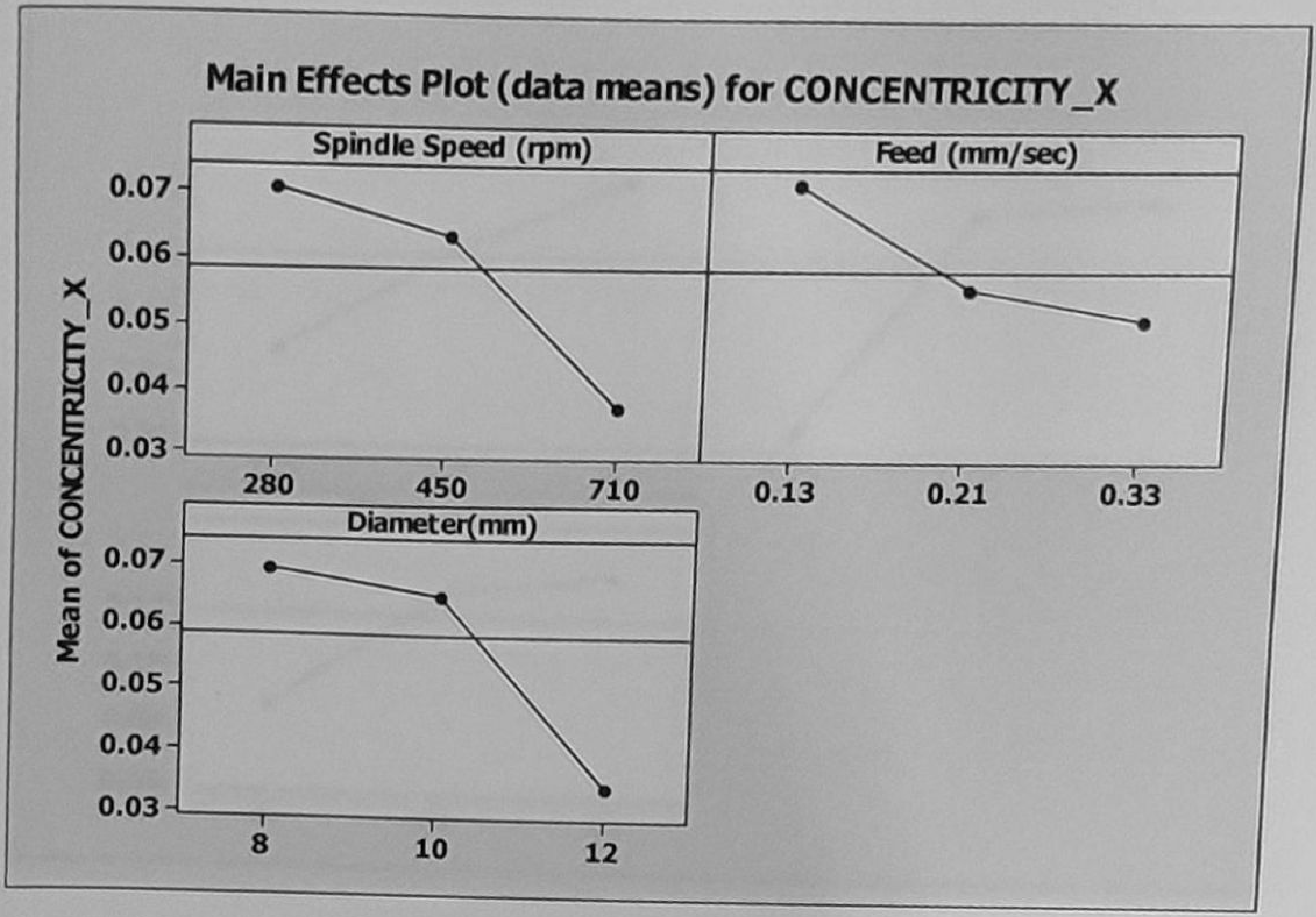


Fig. 5.3Main effects on Concentricity_X

5.6 Main Effect of process parameters on Concentricity_Y

The effect of input parameters on Concentricity along Y-axis is presented in Figure 5.4. All the input parameters have positive effect on the output response. Concentricity along Y-axis is increased with increase in spindle speed, feed and drill diameter.

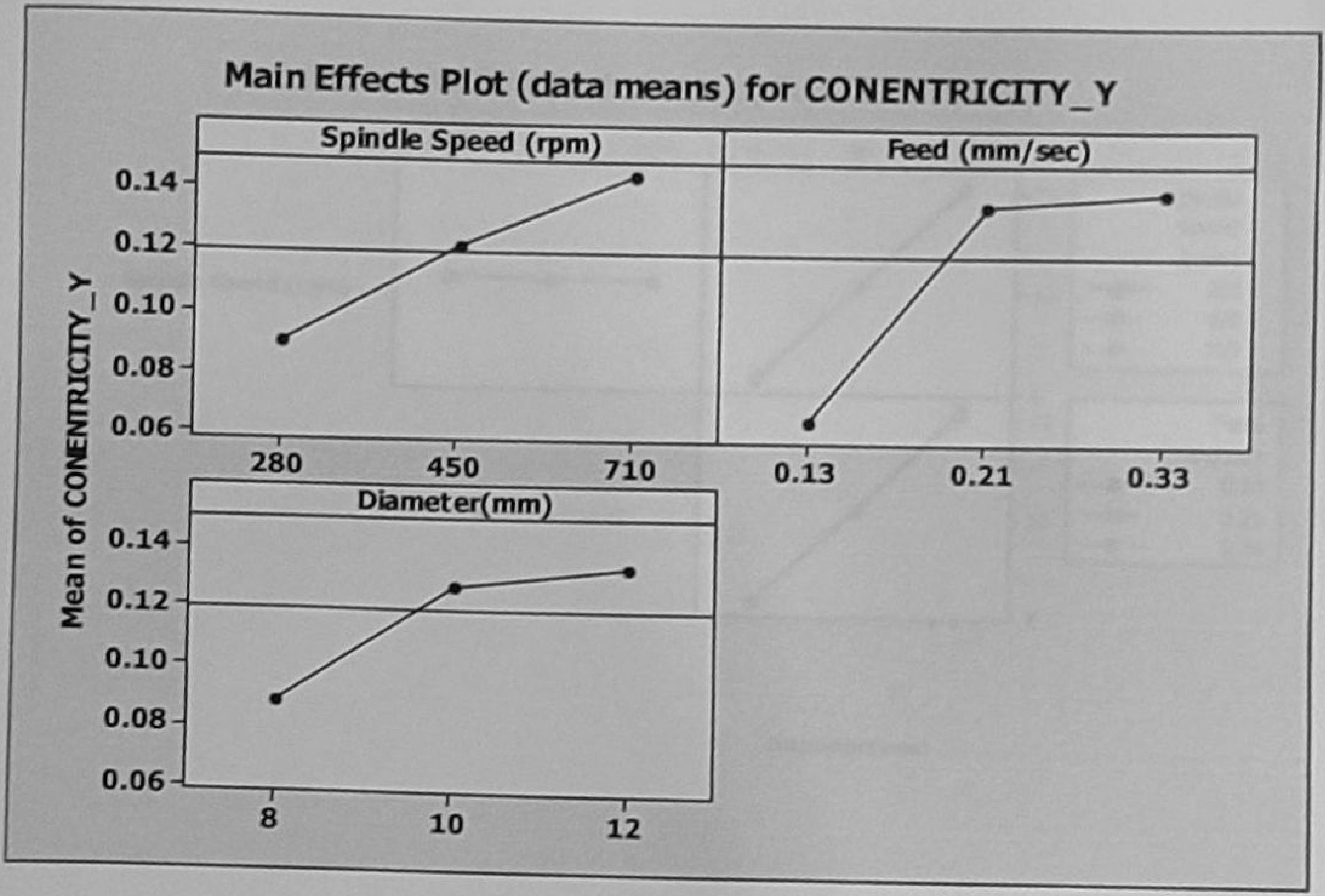


Fig. 5.4Main effects on Concentricity_Y

5.7 Interaction Effect of process parameters on output responses

Interaction plots help in understanding the variation of all the input parameters on the output responses. Figure.5.5 to 5.8 represents the interaction plots of spindle peed, feed and drill diameter on Cylindricity, Circularity, Concentricity_X and Concentricity_Y

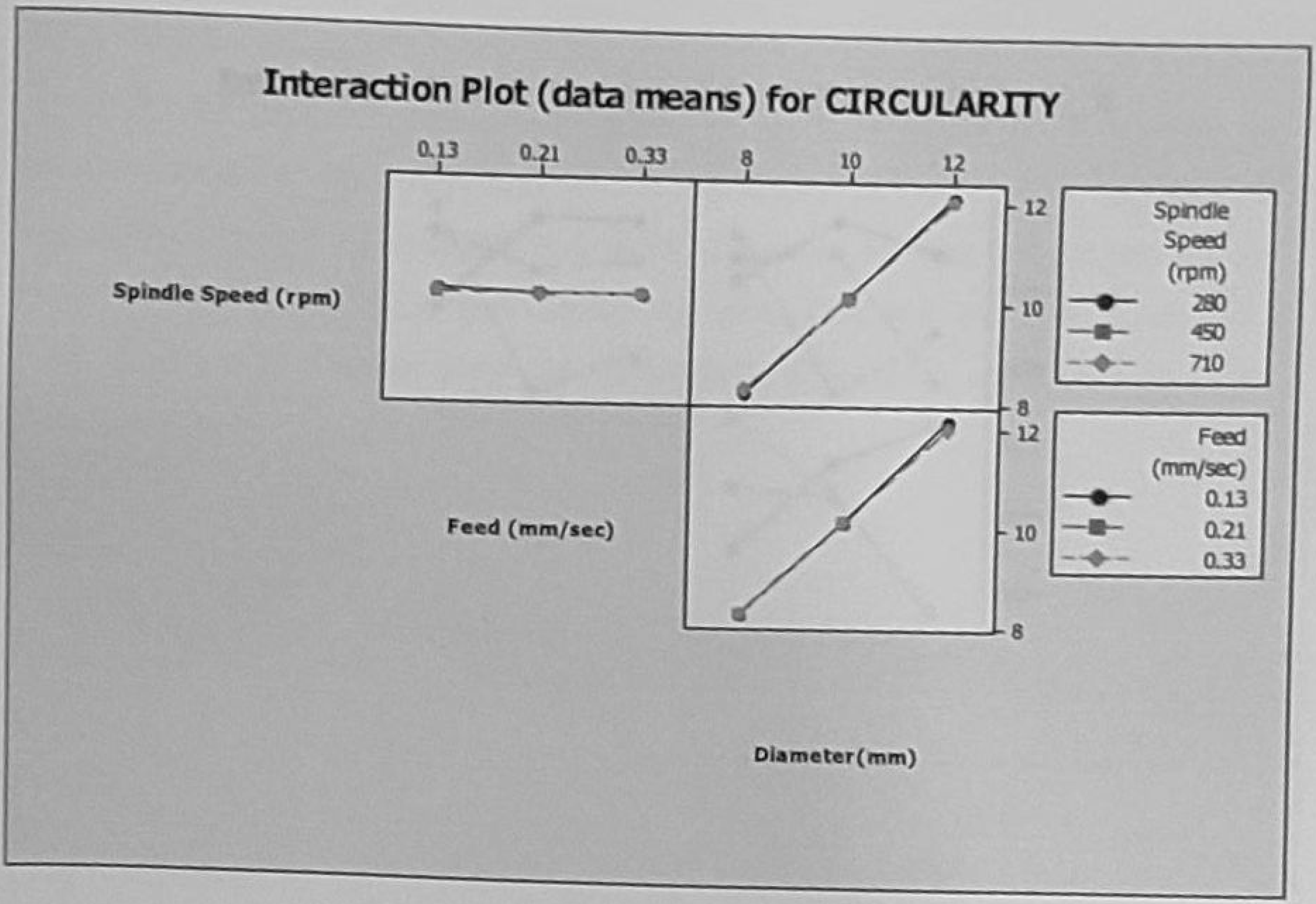


Fig 5.5 Interaction plot for circularity

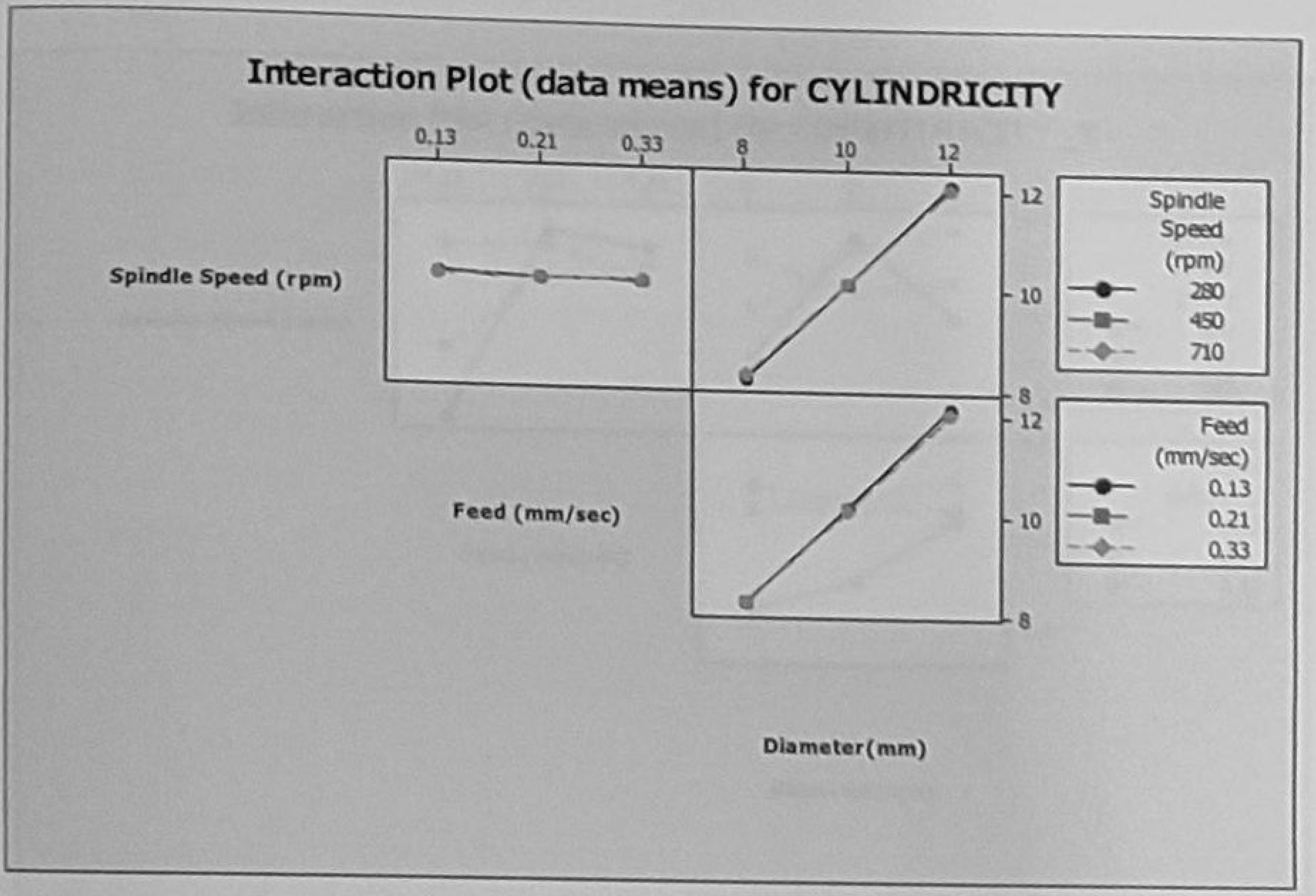


Fig 5.6 Interaction plot for cylindricity

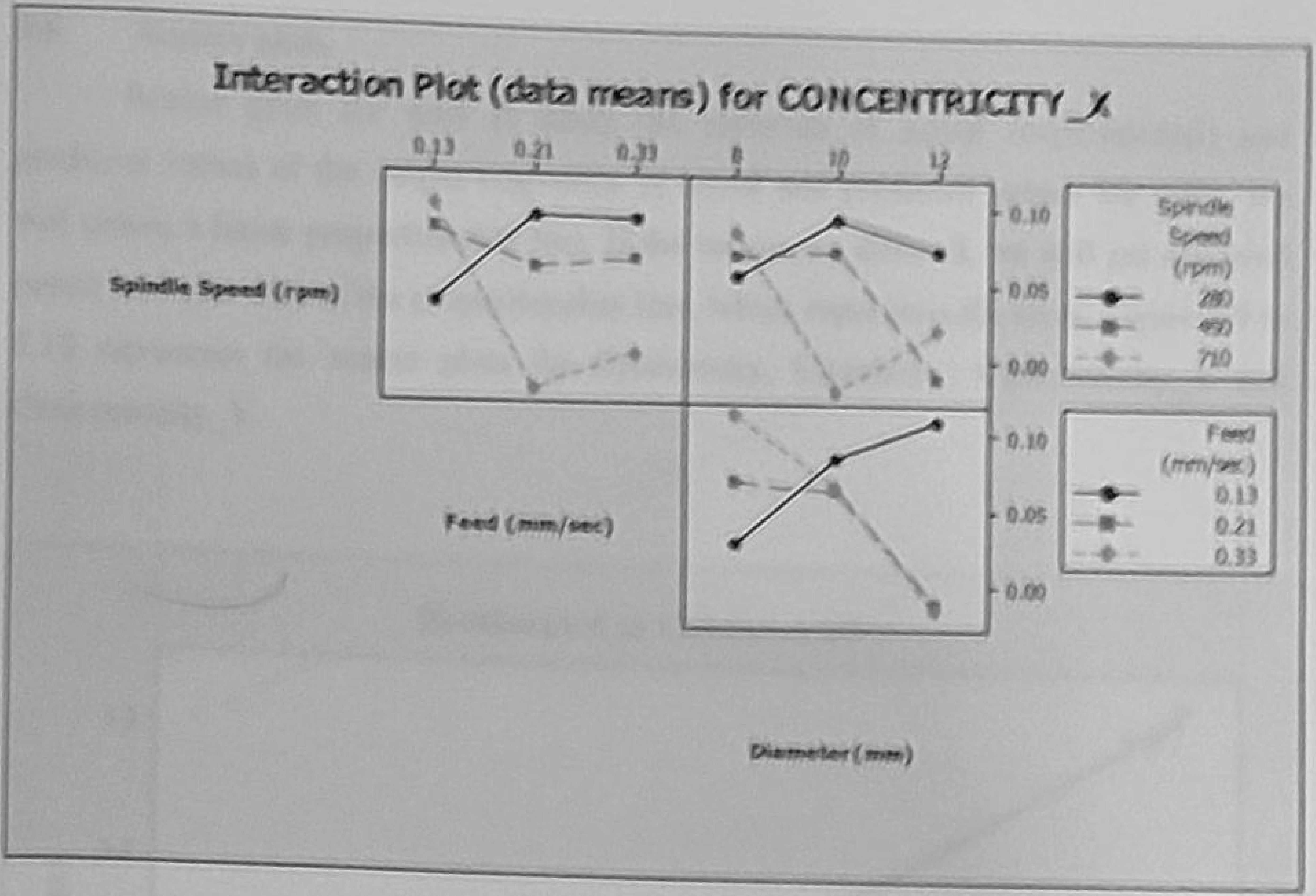


Fig 5.7 Interaction plot for concentricity_X

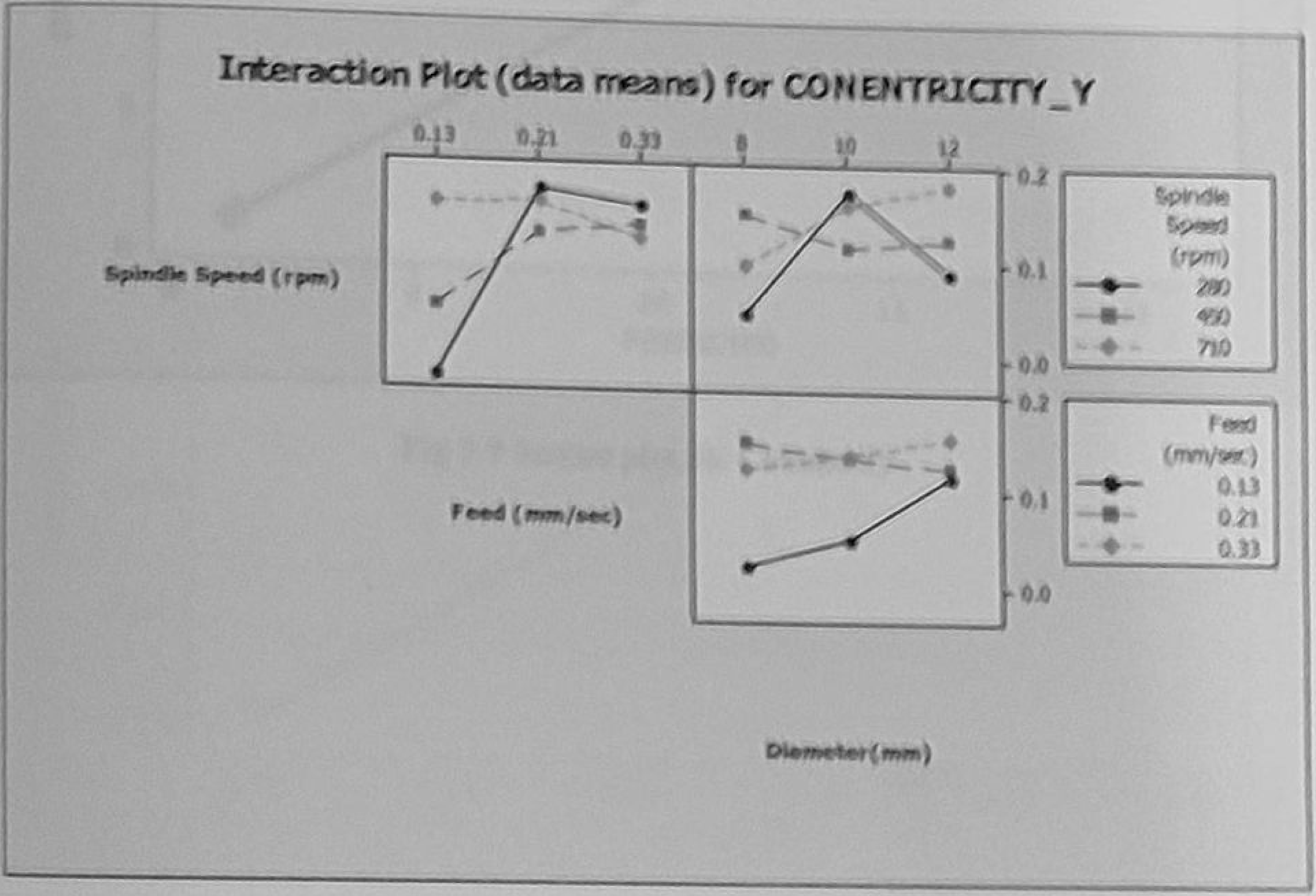


Fig 5.8 Interaction plot for concentricity_Y

5.8 Scatter plots

Scatter plots are used to study the variation of actual (experimental) and predicted values of the output responses. If actual and predicted values are same, we will obtain a linear proportionality line. If the values are differed, we will get scattered points on either side of the proportionality line, which represents the error. Figure 5.9 to 5.12 represents the scatter plots for Cylindricity, Circularity, Concentricity_X and Concentricity_Y.

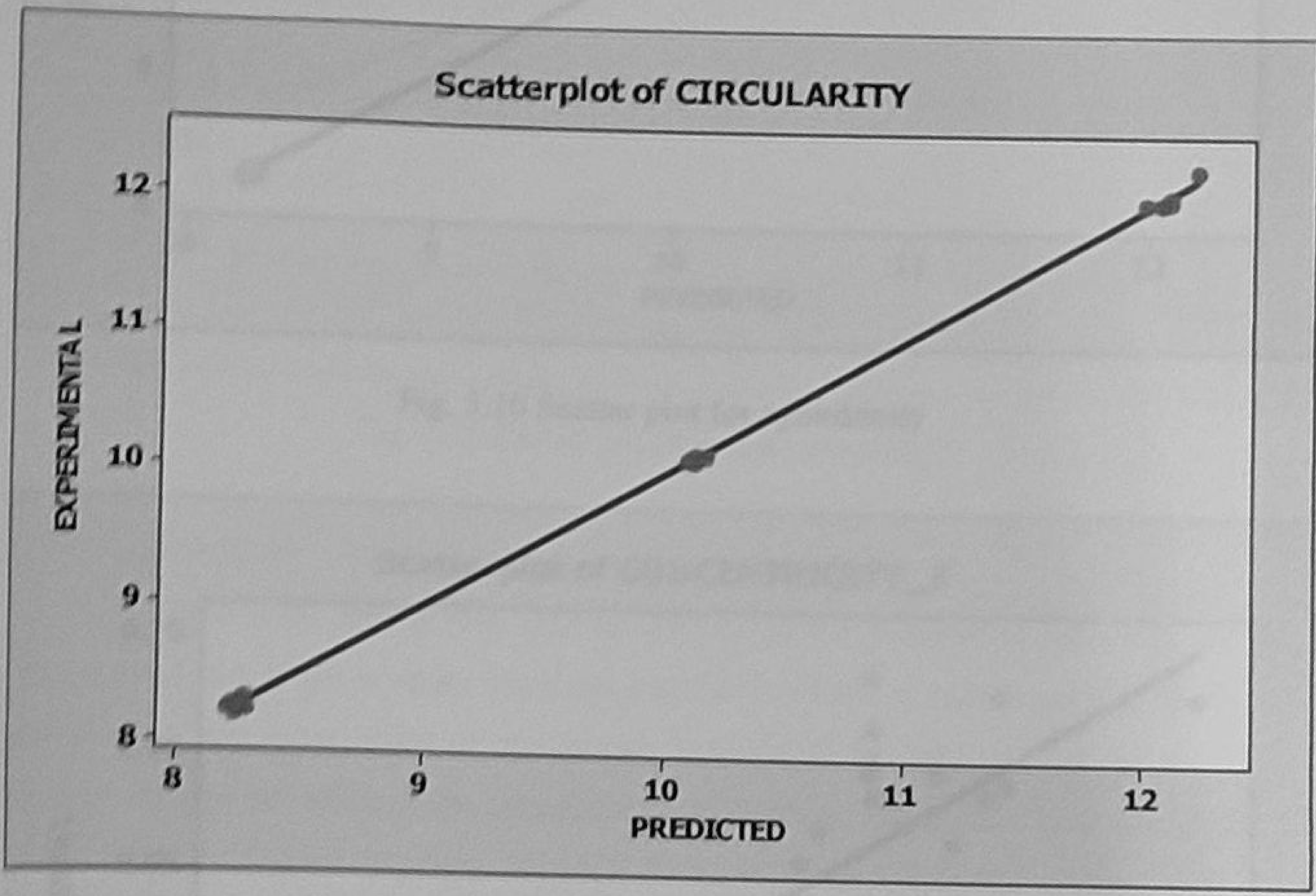


Fig 5.9 Scatter plot for Circularity

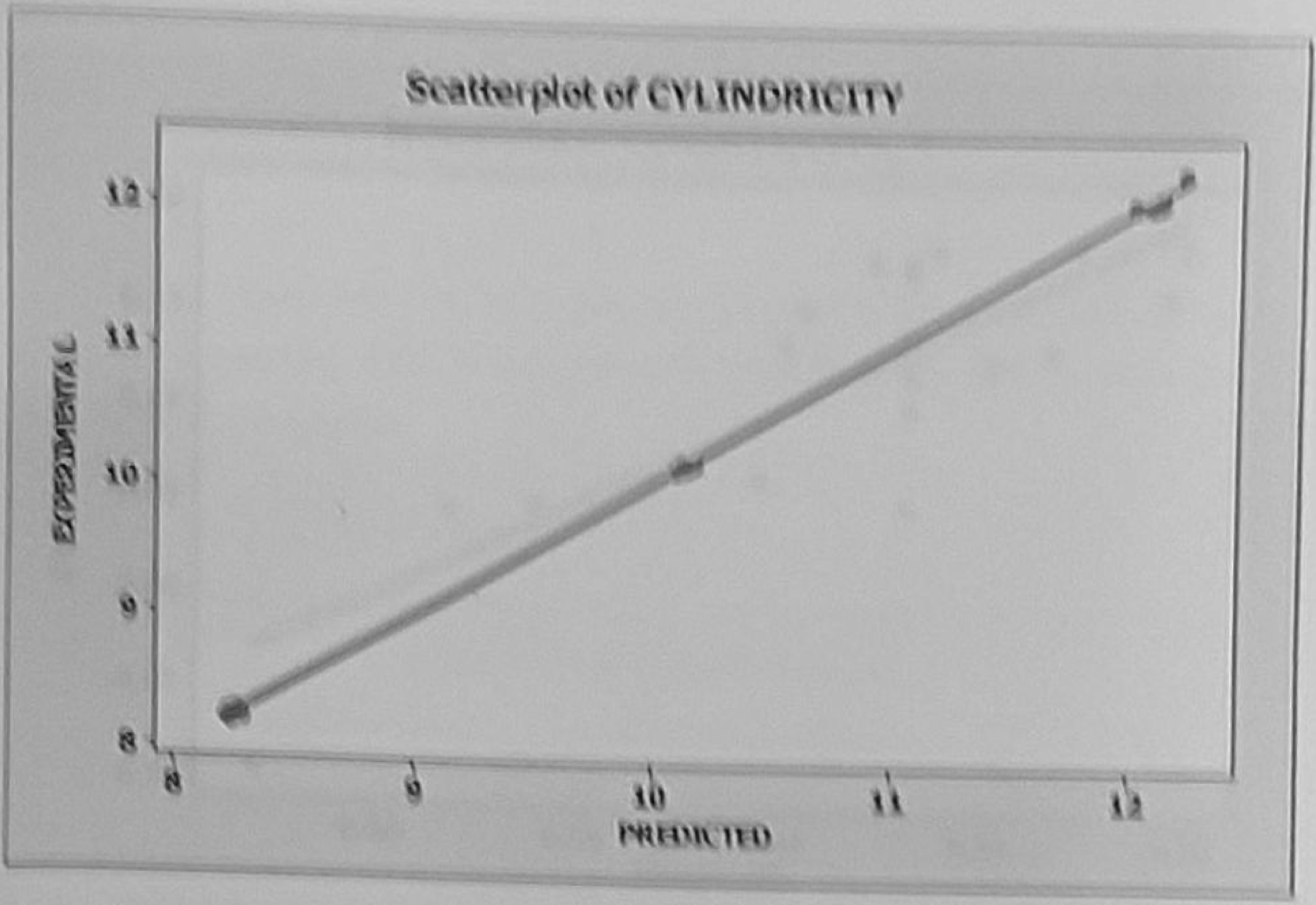


Fig. 5.10 Scatter plot for cylindricity

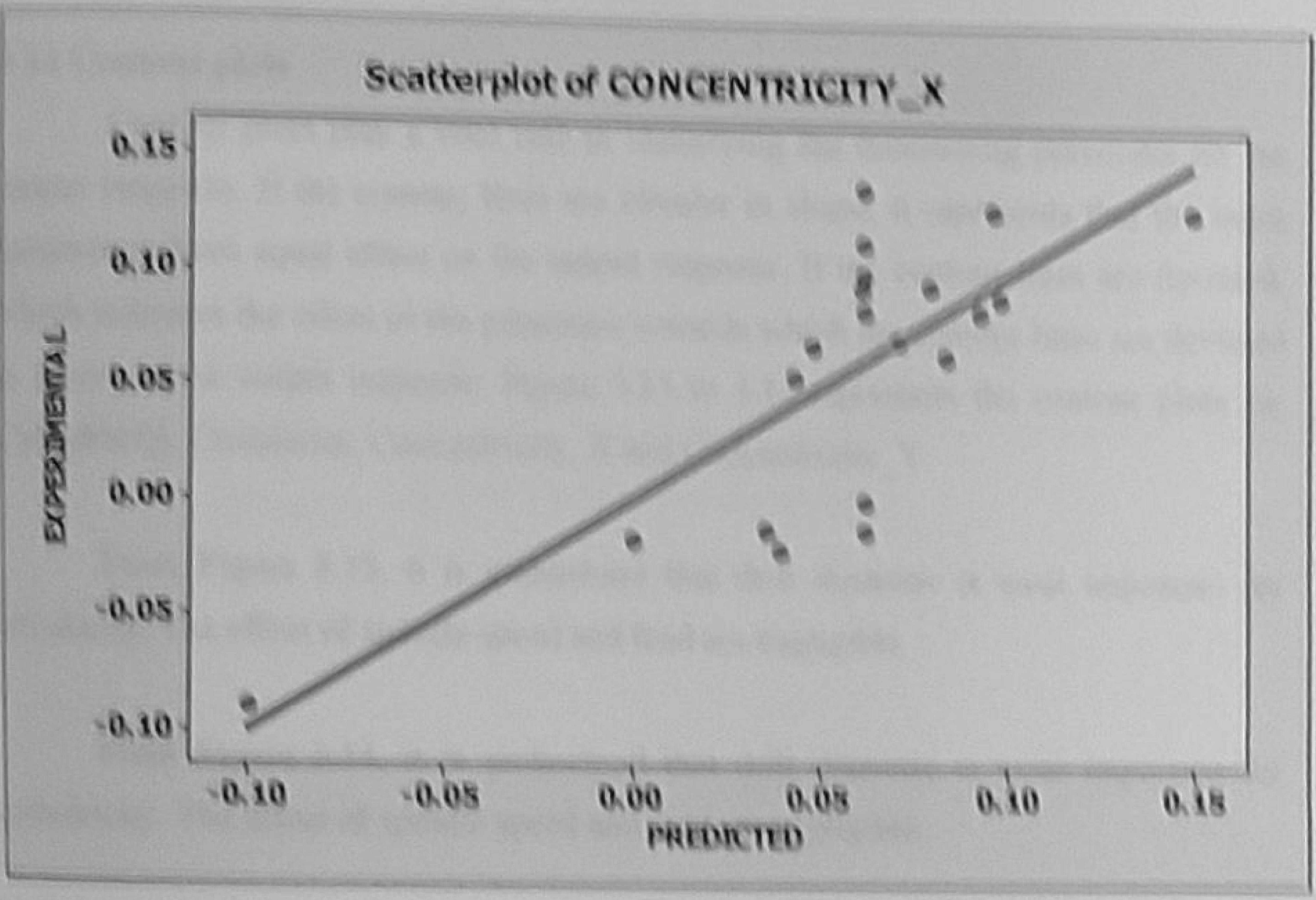


Fig. 5.11 Scatter plot for Concentricity_X

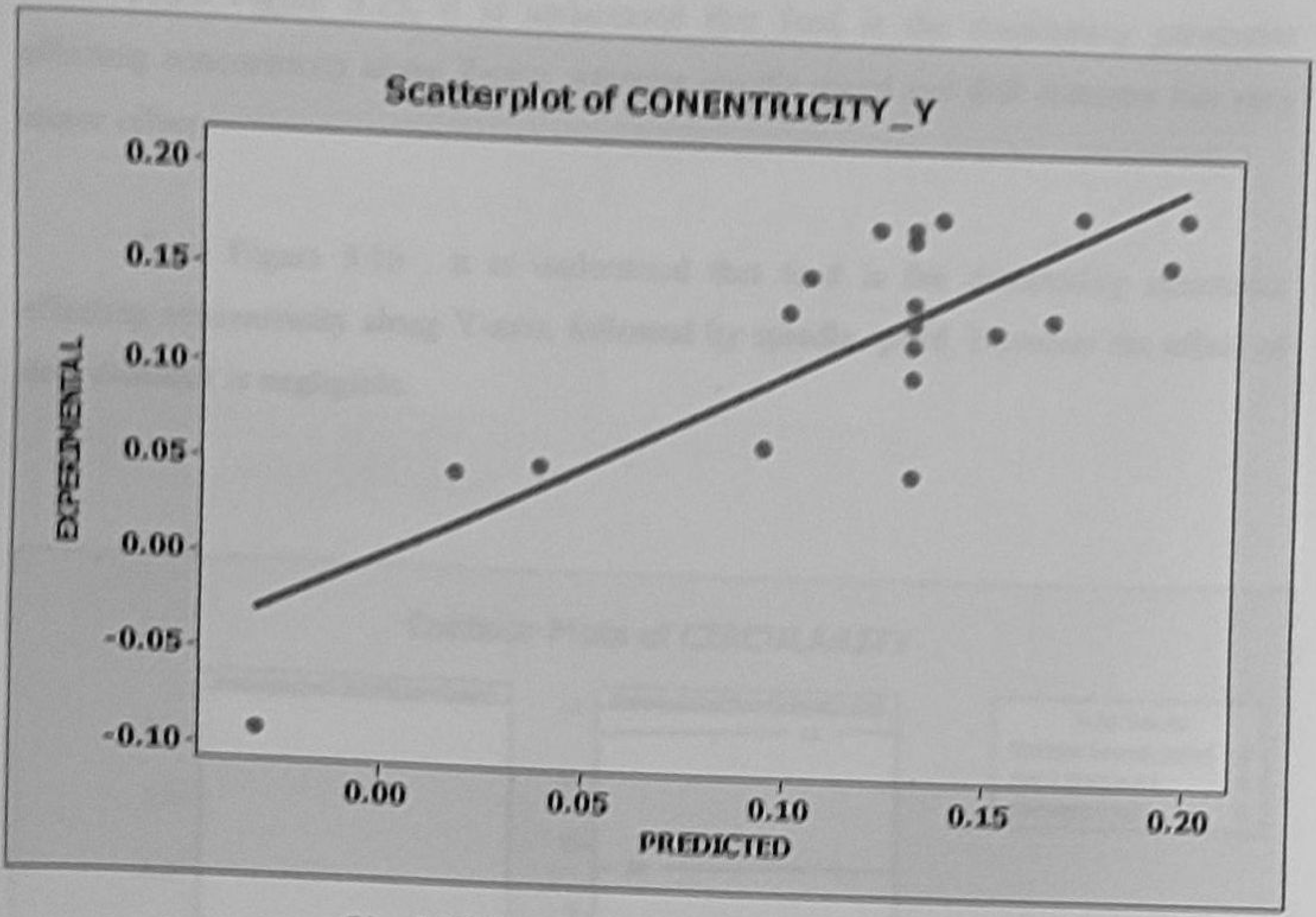


Fig. 5.12 Scatter plot for Concentricity_Y

5.12 Contour plots

Contour plots play a vital role in identifying the dominating parameter on the output response. If the contour lines are circular in shape, it represents that the input parameters have equal effect on the output response. If the contour lines are deviated, which indicates the effect of the parameter towards which the contour lines are deviated is more on the output response. Figure 5.13 to 5.16 represents the contour plots for Cylindricity, Circularity, Concentricity_X and Concentricity_Y.

From Figure 5.13, it is understood that drill diameter is most important for circularity. The effect of spindle speed and feed are negligible.

From Figure 5.14, it is understood that drill diameter is most important for cylindricity. The effect of spindle speed and feed are negligible.

From Figure 5.15, it is understood that feed is the dominating parameter effecting concentricity along X-axis, whereas spindle speed and drill diameter has very minor effect.

From Figure 5.16 , it is understood that feed is the dominating parameter effecting concentricity along Y-axis, followed by spindle speed. However the effect of drill diameter is negligible.

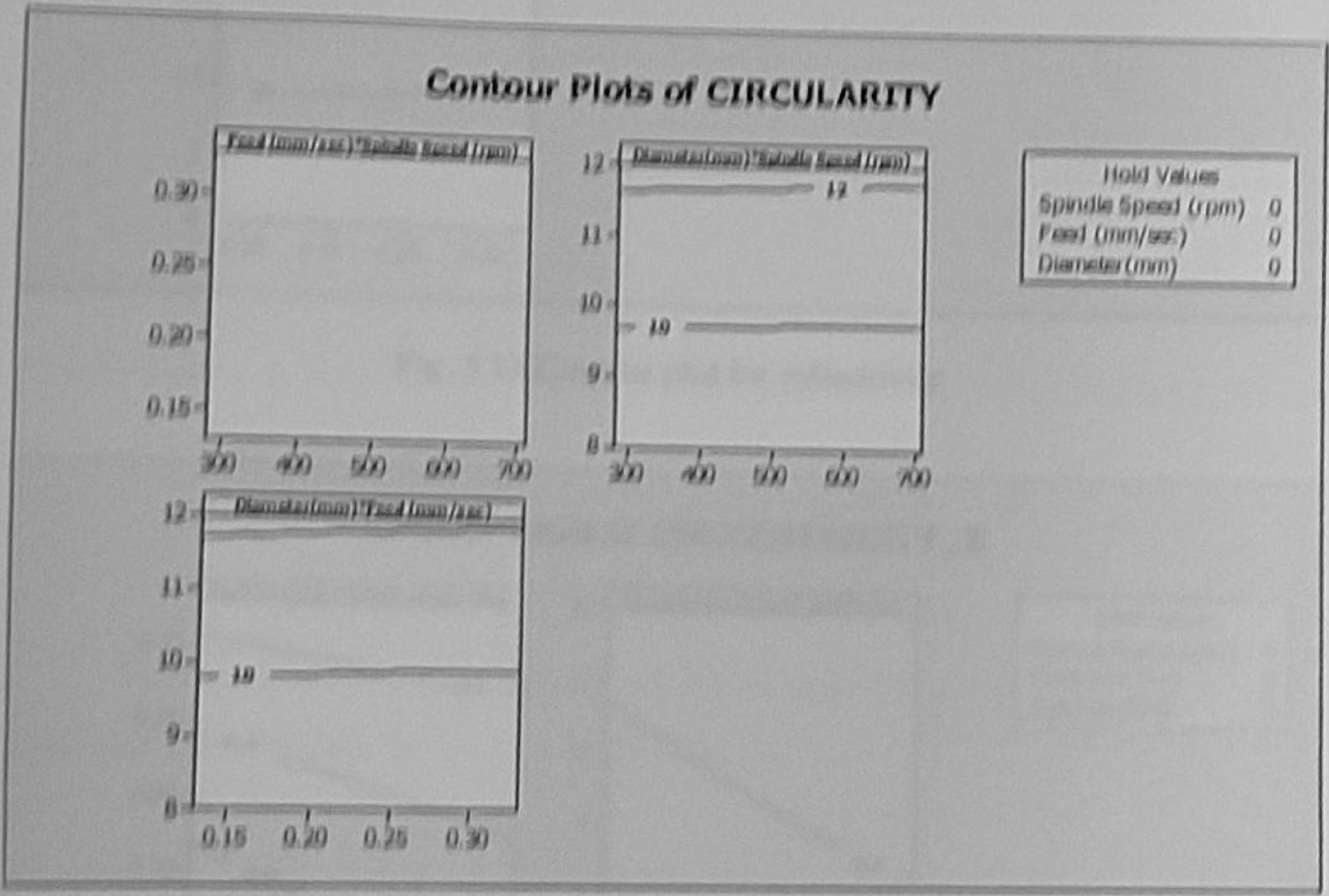


Fig. 5.13 Contour plot for circularity

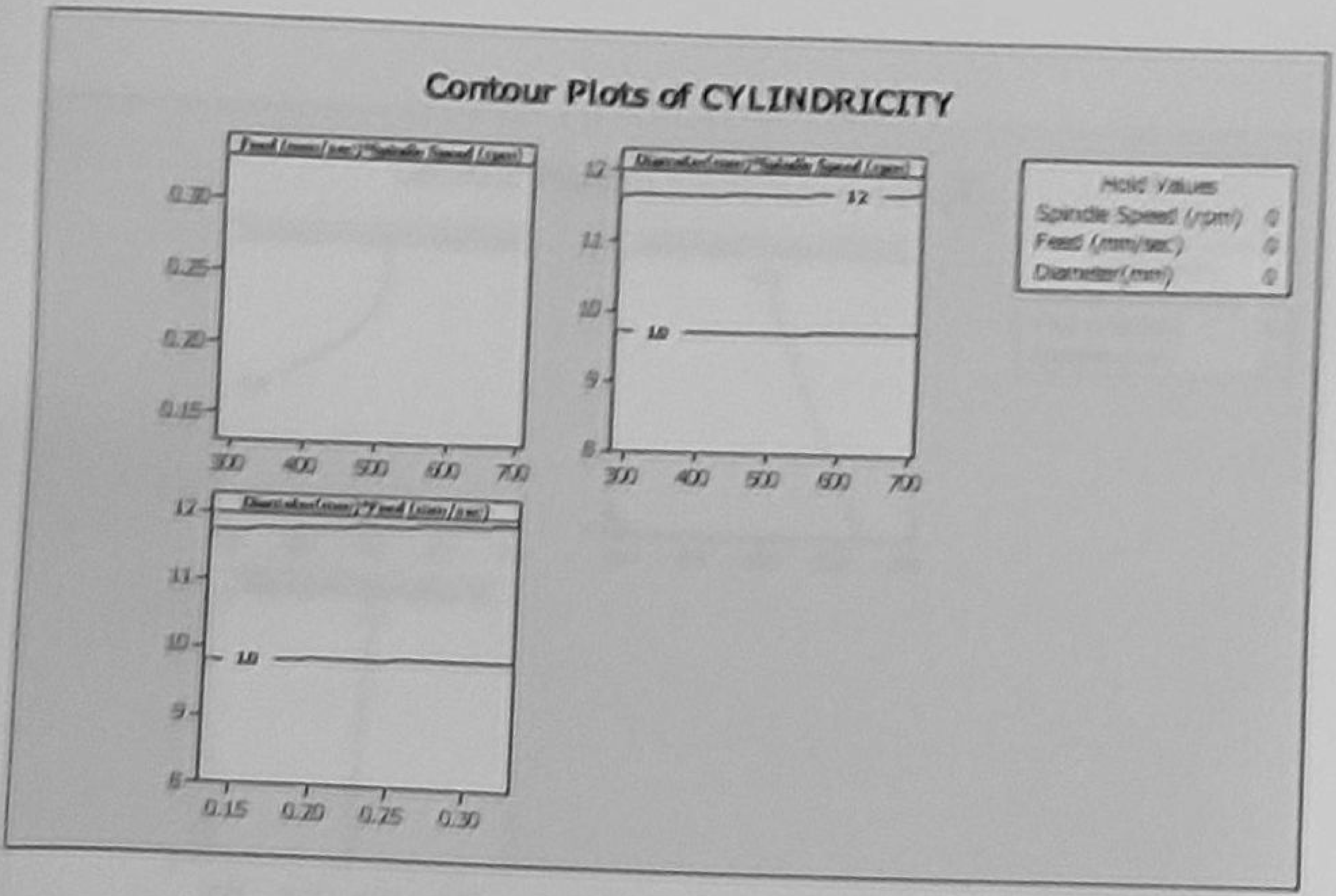


Fig. 5.14 Contour plot for cylindricity

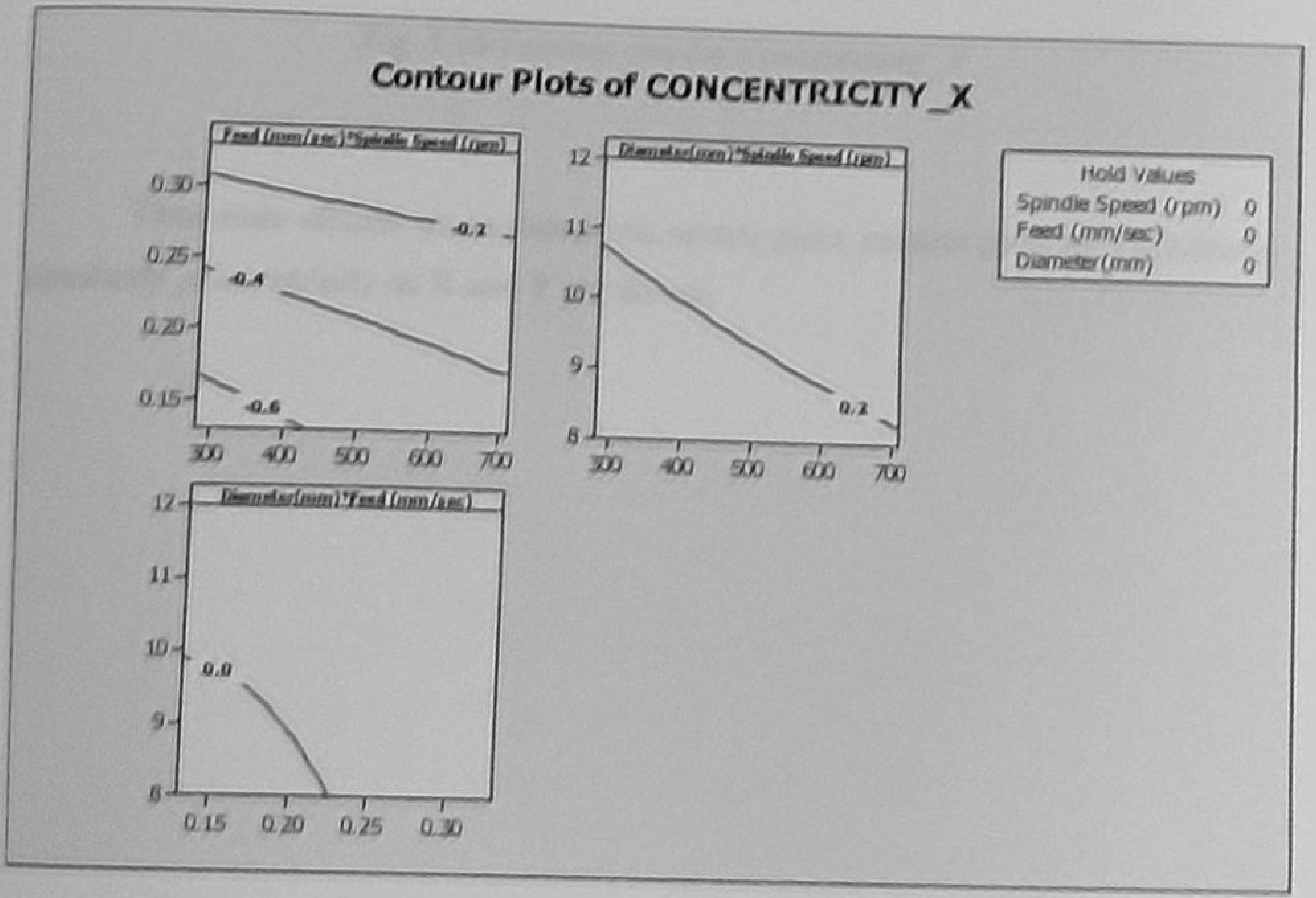


Fig. 5.15 Contour plot for concentricity_X

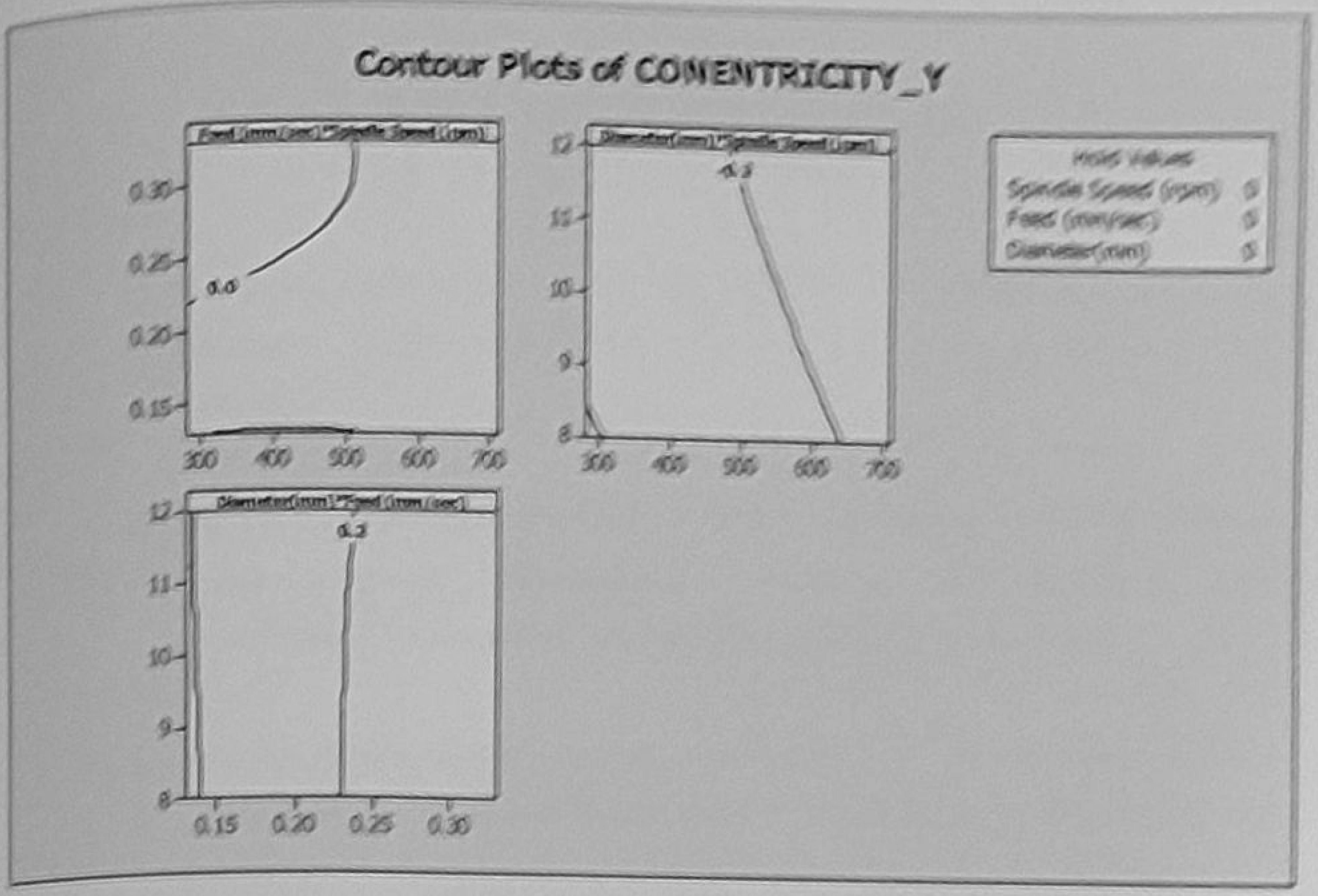


Fig. 5.16 Contour plot for Concentricity_Y

Thus main effects, interaction plots, scatter plots, contour plots for cylindricity, circularity ,concentricity on X and Y are shown.

CHAPTER –VI

CONCLUSIONS

1) Empirical mathematical models are developed for predicting Cylindricity, Circularity, Concentricity_X and Concentricity_Y using Response Surface Method.

2) The variation of input parameters (spindle speed, feed and drill diameter) on output responses (Cylindricity, Circularity, Concentricity_X and Concentricity_Y) are studied and the following observations are made.

- As the spindle speed increases, concentricity_Y are increased, whereas concentricity_X is decreased and there is no variation in Cylindricity and Circularity.

- As the drill feed increases, surface finish and Concentricity_X are reduced. Concentricity_Y is increased. However, there is no effect on Cylindricity and Circularity.

- As the drill diameter increases, circularity, cylindricity and concentricity_Y are increased,whereas concentricity_X is reduced.

3) From the scatter plots, it is understood that the variation of actual and predicted values of the output responses are within the allowable limit.

4) From the Contour plots, it is understood that spindle speed is the mostdominating parameters followed by feed and drill diameter. The present work can be extended by considering burr formation during drilling,which also contributes to the quality characteristics of drilled hole.

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