Comparison of effect of cutting parameters in turning of EN9 material using HSS and HCS Single point cutting tool

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by

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Sangivalasa, Bheemunipatnam (Mandal), Visakhapatnam (District)

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CERTIFICATE

This is to certify that the Project Report entitled " **Comparision of effect of cutting parameters in turning of EN9 material using HSS and HCS single point cutting tool**" has been carried out by Mohit Reny (315126520138),M.PavanKumar (315126520139) ,K.Anusha (315126520094), M Monish Raj (315126520129), L.Suresh(315126520115), my guidance, in partial fulfillment of the requirements of Degree of Bachelor of Mechanical Engineering of ANITS, Visakhapatnam.

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EXTERNAL EXAMINER:

INTERNAL EXAMINER:

ACKNOWLEDGEMENTS

ABSTRACT

The cutting tool plays a very important role in the machining process of a part in production. It not only performs the cutting action but helps in getting required surface finish and accuracy of the part. In order to perform these tasks the tool has to be strong enough to withstand wear resistance and serve for long period of time to produce more number of components with the same accuracy. Machining is important in metal manufacturing process to achieve near-net shape, good dimensional accuracy and for aesthetic requirements.

The experiment is to study, determine and compare the effects of various parameters such as tool temperature, cutting forces, surface roughness and cycle time in turning of EN-9 material with the help of High Speed Steel and High Carbon Steel cutting tools. The above operation is carried out in wet condition using bharat petroleum cutting oil as a lubricant. The cutting operations were carried out on a conventional lathe machine thereby making turning operation at different spindle speed(N) of 300, 200, 125rpm. Also feed of 1rev/min, 0.75rev/min, 0.5rev/min. Depth of cut 1mm,0.75mm,0.5mm. Our project also deals with optimization of cutting parameters on EN-9 specimen in turning operation to obtain maximum MRR , minimum cutting forces and minimum work piece temperature using surface response analysis.

The adequacy of the developed model is checked using response surface method (R.S.M),By using the mathematical model the main and interaction effect of various process parameters on MRR, is studied. The developed model helps in selection of proper machining parameters for the specific material and also helps in achieving the desired material removal rate.

LIST OF CONTENTS

CHAPTER 1:INTRODUCTION

CHAPTER 2: LITERATURE REVIEW
CHAPTER 3: DESIGN OF EXPERIMENTS

CHAPTER 4: EXPERIMENTAL SET UP AND MACHINING

CHAPTER 7: CONCLUSIONS

CHAPTER 8: REFERENCES

LIST OF TABLES

LIST OF FIGURES

Page no

CHAPTER 1
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. Turning is the machining operation that produces cylindrical parts. In its basic form, it can be defined as the machining of an external surface:

- With the work piece rotating.
- With a single-point cutting tool and
- With the cutting tool feeding parallel to the axis of the work piece and at a distance that will remove the outer surface of the work.
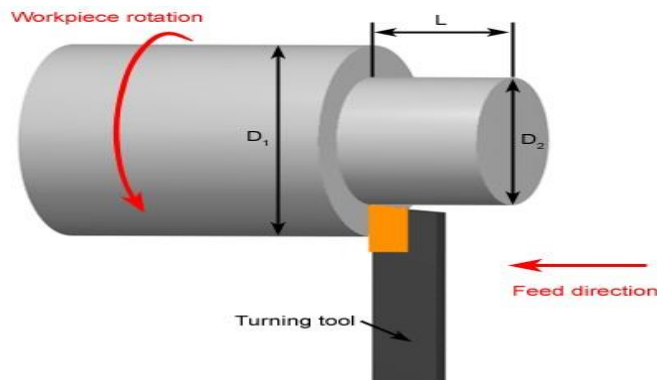
Figure 1.1: Adjustable parameters in turning operation

Taper turning is practically the same, except that the cutter path is at an angle to the work axis. Similarly, in contour turning, the distance of the cutter from the work axis is varied to produce the desired shape. Even though a single-point tool is specified, this does not exclude multiple-tool setup as a single-point which is often employed in turning. In such setups, each tool will operate independently as a single cutting tool.

1.2 ADJUSTABLE CUTTING PARAMETERS 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 hav e a large influence, of course, but these three are the ones the operator can change by adjusting the controls, right on the machine.

1.2.1 Speed:

Speed always refers to the spindle and the work piece. When it is stated in revolutions per minute (rpm) it defines the speed of rotation. But, the important feature for
a particular turning operation is the surface speed, or 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

$$v = \pi DN/1000$$

Here, v is the cutting speed in turning in m/min,

D is the initial diameter of the work piece in mm,

N is the spindle speed in r.p.m.

1.2.2 Feed:

Feed always refers to the cutting tool, and it is the rate at which the tool advances along its cutting path. 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.

$$F_m = f \times N \ (mm/\text{min})$$

Here,

F_m is the feed in mm per minute,

f - Feed in mm/rev and

N - Spindle speed in r.p.m.

1.2.3 Depth of Cut:

Depth of cut is practically self explanatory. It is 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. 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

$$D_{cut} = \frac{D - d}{2}$$

D_{cut} - Depth of cut in mm

D   - Initial diameter of the work piece

d   - Final diameter of the work piece

1.3 CUTTING TOOLS FOR LATHES

1.3.1 Tool Geometry

For cutting tools, geometry depends mainly on the properties of the tool material and the work material. The standard terminology is shown in the following figure1.2. For single point tools, the most important angles are the rake angles and the end and side relief angles

1.3.1(a) Flank

A flat surface of a single-point tool that is adjacent to the face of the tool. During turning, the side flank faces the direction that the tool is fed into the work piece, and the end flank passes over the newly machined surface.

1.3.1(b) Face

The flat surface of a single point tool through which, the work piece rotates during turning operation. On a typical turning setup, the face of the tool is positioned upwards.
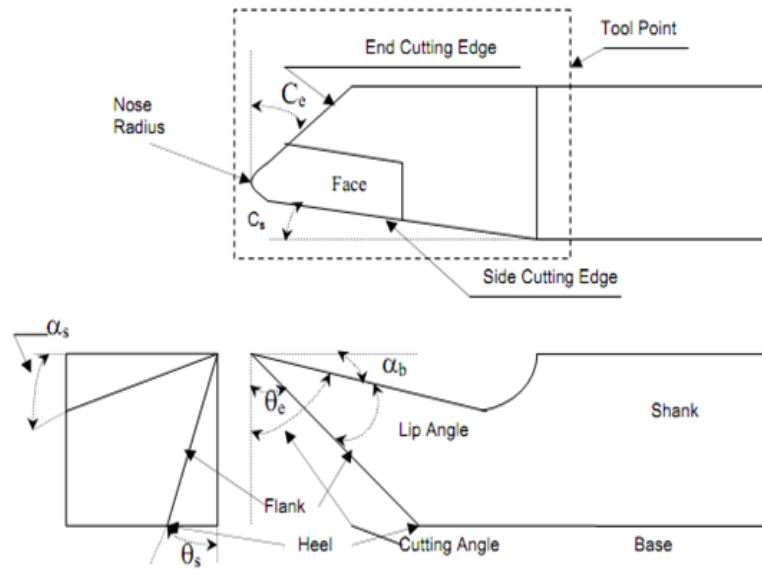
Fig 1.2: Geometry of tool

1.3.1(c) Back rake angle

If viewed from the side facing the end of the work piece, it is the angle formed by the face of the tool and a line parallel to the floor. A positive back rake angle tilts the tool face back, and a negative angle tilts it forward and up

1.3.1(d)(Side rake angle

If viewed from behind the tool looking down the length of the tool holder, it is the angle formed by the face of the tool and the centre line of the work piece. A positive side rake angle tilts the tool face down toward the floor, and a negative angle tilts the face up and toward the work piece.

1.3.1(e) Side cutting edge angle

If viewed from above looking down on the cutting tool, it is the angle formed by the side flank of the tool and a line perpendicular to the work piece centreline. A positive side cutting edge angle moves the side flank into the cut, and a negative angle moves the side flank out of the cut.

1.3.1(f) End cutting edge angle

If viewed from above looking down on the cutting tool, it is the angle formed by the end flank of the tool and a line parallel to the work piece centreline. Increasing the end cutting

edge angle tilts the far end of the cutting edge away from the work piece.

1.3.1(g) Side relief angle

If viewed from behind the tool looking down the length of the tool holder, it is the angle formed by the side flank of the tool and a vertical line down to the floor. Increasing the side relief angle tilts the side flank away from the work piece.

1.3.1(h) End relief angle

If viewed from the side facing the end of the work piece, it is the angle formed by the end flank of the tool and a vertical line down to the floor. Increasing the end relief angle tilts the end flank away from the work piece.

1.3.1(i) Nose radius:

It is the rounded tip on the cutting edge of a single point tool. A zero degree nose radius creates a sharp point of the cutting tool.

1.3.1(j) Lead angle:

It is the common name for the side cutting edge angle. If a tool holder is built with dimensions that shift the angle of an insert, the lead angle takes this change into consideration. The back rake angle affects the ability of the tool to shear the work material and form the chip. It can be positive or negative. Positive rake angles reduce the cutting forces resulting in smaller deflections of the work piece, tool holder, and machine. If the back rake angle is too large, the strength of the tool is reduced as well as its capacity to conduct heat. In machining hard work materials, the back rake angle must be small, even negative for carbide and diamond tools. The higher the hardness, the smaller will be the back rake angle. For high-speed steels, back rake angle is normally chosen in the positive range.

1.4 CUTTING TOOL MATERIALS

The classes of cutting tool materials currently in use for machining operation are high-speed tool steel, cobalt-base alloys, cemented carbides, ceramic, and polycrystalline cubic boron nitride and polycrystalline diamond. Different machining applications require different cutting tool materials. 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

Some common cutting tool materials are described below:

1.4.1 Carbon steels

Carbon steels have been used since the 1880s for cutting tools. However carbon steels start to soften at a temperature of about 180$^\text{o}$C. This limitation means that such tools are rarely used for metal cutting operations. Plain carbon steel tools, containing about 0.9% carbon and about 1% manganese, hardened to about 62 Rc, are widely used for Woodworking and they can be used in a router to machine aluminium sheet up to about 3mm thick.

1.4.2 High speed steels (HSS)

HSS tools are so named because they were developed to cut at higher speeds. Developed around 1900 HSS are the most highly alloyed tool steels. The tungsten (T series) was developed first and typically contains 12 - 18% tungsten, plus about 4% chromium and 1-5% vanadium. Most grades contain about 0.5% molybdenum and most grades contain 4-12% cobalt. It was soon discovered that molybdenum (smaller proportions) could be substituted for most of the tungsten resulting in a more economical formulation which

had better abrasion resistance than the T series and undergoes less distortion during heat treatment. Consequently about 95% of all HSS tools are made from M series grades. These contain 5 - 10% molybdenum, 1.5 - 10% tungsten, 1 - 4% vanadium, 4% Chromium and many grades contain 5 - 10% cobalt.HSS tools are tough and suitable for interrupted cutting and are used to manufacture tools of complex shape such as drills, reamers, taps, dies and gear cutters. Tools may also be coated to improve wear resistance. HSS accounts for the largest tonnage of tool materials currently used. Typical cutting speeds: 10 - 60 m/min.

Fig 1.3: High speed steel(HSS) tool

1.4.3 Cast Cobalt alloys

Introduced in early 1900s these alloys have compositions of about 40 - 55% cobalt, 30% chromium and 10 - 20% tungsten and are not heat treatable. Maximum hardness values of 55 - 64 Rc. They have good wear resistance but are not as tough as HSS but can be used at somewhat higher speeds than HSS. Now only in limited use.

1.4.4 Carbides

Also known as cemented carbides or sintered carbides were introduced in the 1930s and have high hardness over a wide range of temperatures, high thermal conductivity, high Young's modulus making them effective tool and die materials for a range of applications. The two groups used for machining are tungsten carbide and titanium carbide; both types may be coated or uncoated. Tungsten carbide particles (1 to 5 micrometres) are bonded together in a cobalt matrix using powder metallurgy. The powder is pressed and sintered to the required insert shape. Titanium and niobium carbides may also be included to impart special properties. A wide range of grades are available for different applications. Sintered carbide tips are the dominant type of material used in metal cutting. The proportion of cobalt (the usual matrix material) present has a

significant effect on the properties of carbide tools. 3 - 6% matrix of cobalt gives greater hardness while 6 - 15% matrix of cobalt gives a greater toughness while decreasing the hardness, wear resistance and strength. Tungsten carbide tools are commonly used for machining steels, cast irons and abrasive non-ferrous materials. Titanium carbide has a higher wear resistance than tungsten but is not as tough. With a nickel-molybdenum alloy as the matrix, TiC is suitable for machining at higher speeds than those which can be used for tungsten carbide. Typical cutting speeds are: 30 - 150 m/min or 100 - 250 when coated.

1.4.4 High Carbide Steels (HCS)

Generally, the high carbon steels contain from 0.60 to 1.00% C with manganese contents ranging from 0.30 to 0.90%. The pearlite has a very fine structure, which makes the steel very hard. Unfortunately this also makes the steel quite brittle and much less ductile than mild steel.

Fig 1.4:High Carbide Steel (HCS) Single Point Cutting Tool

Medium and high carbon steels are widely used in many common applications. Increasing carbon as the primary alloy for the higher strength and hardness of steels is usually the most economical approach to improved performance. However, some of the effects of elevated carbon levels include reduced weldability, ductility and impact toughness. When these reduced properties can be tolerated, the increased strength and hardness of the higher carbon materials can be used to a significant advantage. Common applications of higher carbon steels include forging grades, rail steels, spring steels (both flat rolled and round), pre-stressed concrete, wire rope, tire reinforcement, wear resistant steels (plates

and forgings), and high strength bar.

1.5 TURNING MACHINES

The turning machines are, of course, every kind of lathes. Lathes used in manufacturing can be classified as engine, turret, automatics, and numerical control etc. 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 centre distance, but swings up to 50 inches and centre distances up to 12 feet are not uncommon.
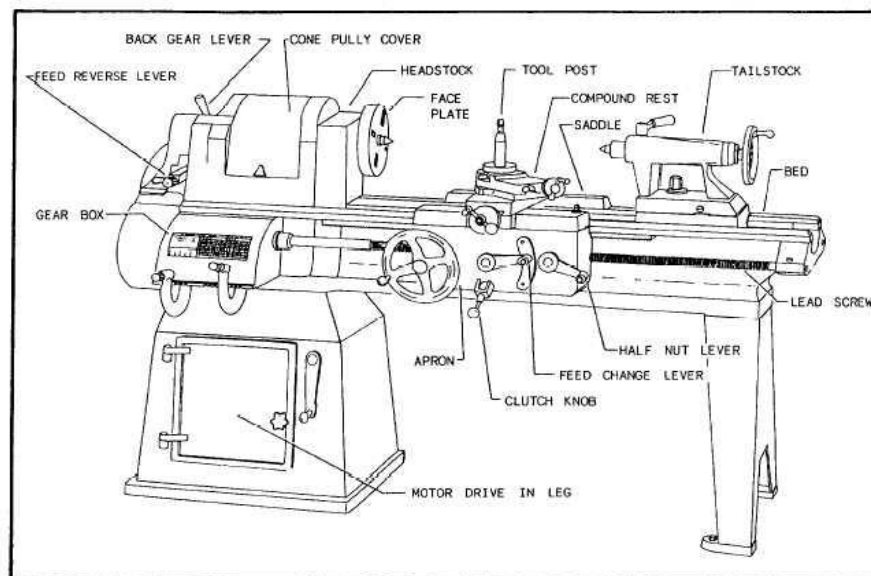
Fig 1.5: Engine lathe

1.5.1 Turret Lathes

In a turret lathe, a longitudinally feed able, 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 annually or by power, to provide feed for the tools. When the turret assembly is backed away from the spindle by means of a capstan wheel; the turret indexes automatically at the end of its movement, thus, bring each of the six tools into operating position. The square turret on the cross slide can be rotated manually about a vertical axis to bring each of the four tools into operating position. On most machines, the turret can be moved transversely, either manually or by power, by means of the cross slide, and longitudinally through power or manual operation of the carriage. In most cased, a fixed tool holder also is added to the back end of the cross slide; this often carries a parting tool. Through these basic features of a turret lathe, a number of tools can be set on the machine and then

quickly be brought successively into working position so that a complete part can be machined without the necessity for further adjusting, changing tools, or making measurements.
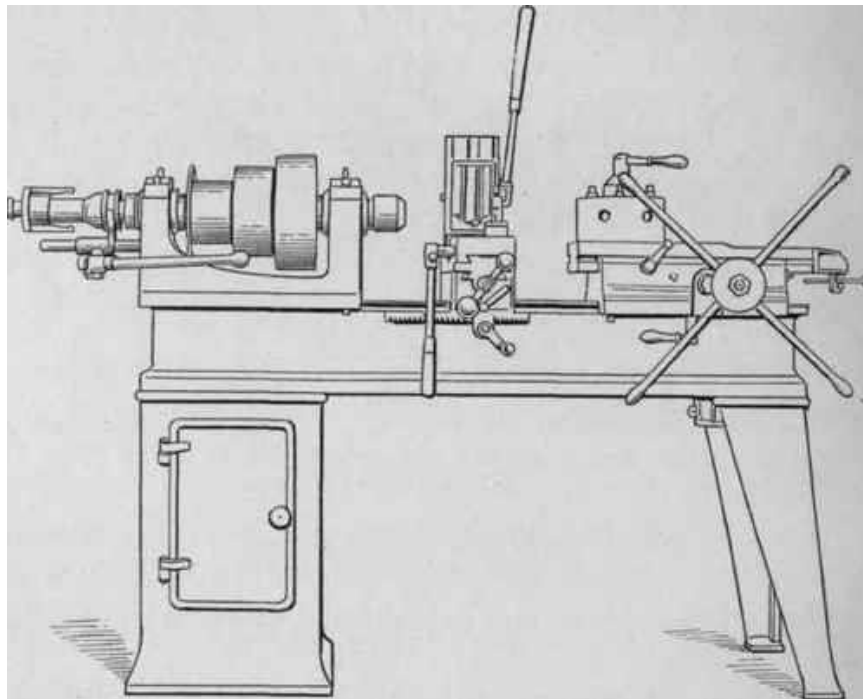
Figure1.6: Turret lathe

1.5.2 Single-Spindle Automatic Screw Machines

There are two common types of single-spindle screw machines, One, an American development and commonly called the turret type (Brown & Sharp), is shown in the following figure1.5. The other is of Swiss origin and is referred to as the Swiss type. The Brown & Sharp screw machine is essentially a small automatic turret lathe, designed for bar stock, with the main turret mounted on the cross slide. All motions of the turret, cross slide, spindle, chuck, and stock-feed mechanism are controlled by cams. The turret cam is essentially a program that defines the movement of the turret during a cycle. These machines usually are equipped with an automatic rod feeding magazine that feeds a new length of bar stock into the collect as soon as one rod is completely used
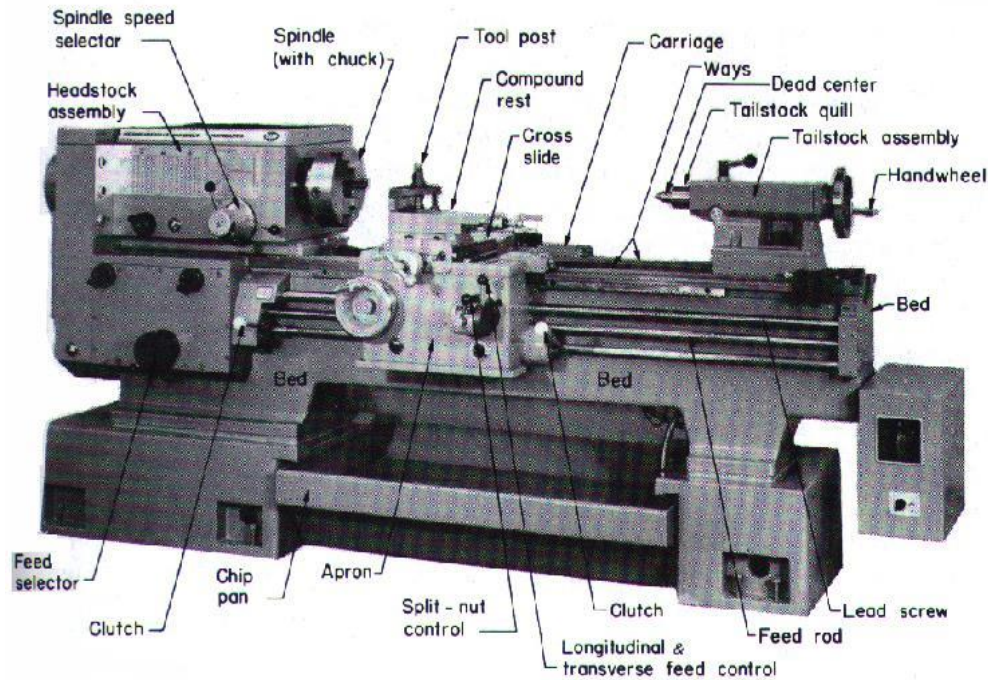
Fig 1.7: Single spindle automatic screw lathe

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. Monochromatic plane wave with an angle of incidence with respect to the normal to the surface; multi-scattering and shadowing effects are neglected. The photo-sensor of a CCD camera placed in the focal plane of a Fourier lens is used for recording speckle patterns. Assuming Cartesian coordinates x,y,z, a rough surface can be represented by its ordinates $Z(x,y)$ with respect to an arbitrary datum plane having transverse coordinates (x,y,z). Then the rms value of surface roughness can be defined and calculated roughness values.

a. 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.

b. 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.

1.6 Temperature Gun Measurement

Temperature guns have electronic sensors that enable them to collect the amount of heat energy coming from a given object whose temperature would otherwise be difficult to measure. These guns often use infrared beams and you only have to aim at the object whose temperature you are interested in measuring without having to touch it. The sensors have the capability to collect the accurate temperature provided the gadget is functional

Fig 1.8:Temperature gun

There are however some basics that you must know in order to use these temperature guns correctly.

First, the temperature gun uses beams to collect information on the heat energy that is coming from a given object. Thus, the gun does not state whether the heat is coming from the intended object or the surroundings. This means that in order to collect the right temperature measurement, you will have to ensure that you point the gun directly at the object whose temperature you intend to measure. You need to be as close as possible to avoid reading other heat waves that may interfere with your reading's accuracy. The gun will only read the heat energy on the area where it is pointing, and for accuracy, you must aim directly at the object whose temperature you intend to measure.

1.7 Turning dynamometer

A machine tool dynamometer is a multi-component dynamometer that is used to measure forces during the use of the machine tool. Empirical calculations of these forces can be cross-checked and verified experimentally using these machine tool dynamometers.

Fig 1.9: Turning Dynamometer

With advances in technology, machine-tool dynamometers are increasingly used for the accurate measurement of forces and for optimizing the machining process. These multi-component forces are measured as an individual component force in each co-ordinate, depending on the coordinate system used. The forces during machining are dependent on depth of cut, feed rate, cutting speed, tool material and geometry, material of the work piece and other factors such as use of lubrication/cooling during machining.

Turning dynamometers may be strain gauge or piezoelectric type and may be of one, two or three dimensions capable to monitor all of PX, PY and PZ. For ease of manufacture and low cost, strain gauge type turning dynamometers are widely used and preferably of 2 – D (dimension) for simpler construction, lower cost and ability to provide almost all the desired force values.

1.8 INTRODUCTION TO MINITAB

Minitab is a statistics package. It was developed at the Pennsylvania State University by researchers Barbara F. Ryan, Thomas A. Ryan, Jr., and Brian L. Joiner in 1972. Minitab began as a light version of OMNITAB, a statistical analysis program by NIST. It can be used for learning about statistics as well as statistical research. Statistical analysis computer applications have the advantage of being accurate, reliable, and generally faster than computing statistics and drawing graphs by hand. Minitab is relatively easy to use once you know a few fundamentals.

Minitab is distributed by Minitab Inc, a privately owned company headquartered in State College, Pennsylvania, with subsidiaries in Coventry, England(Minitab Ltd.), Paris, France (Minitab SARL) and Sydney, Australia (Minitab Pty.).

Today, Minitab is often used in conjunction with the implementation of six sigma,CMMI and other statistics-based process improvement methods. Minitab 16, the latest version of the software, is available in 7 languages: English, French, German, Japanese, Korean, Simplified Chinese, & Spanish.

Minitab is statistical analysis software. It can be used for learning about statistics as well as statistical research. Statistical analysis computer applications have the advantage of being accurate, reliable, and generally faster than computing statistics and drawing graphs by hand. Minitab is relatively easy to use once you know a few fundamentals.

Minitab Inc. produces two other products that complement Minitab 16: Quality Trainer, an eLearning package that teaches statistical tools and concepts in the context of quality improvement that integrates with Minitab 16 to simultaneously develop the user's statistical knowledge and ability to use the Minitab software and Quality Companion 3, an integrated tool for managing Six Sigma and Lean Manufacturing projects that allows Minitab data to be combined with management and governance tools and documents.

Minitab has two main types of files, projects and worksheets. Worksheets are files that are made up of data; think of a spreadsheet containing variables of data. Projects are made up of the commands, graphs and worksheets. Every time you save a Minitab project you will be saving graphs, worksheets and commands. However each one of the elements can be saved individually for use in other documents or Minitab projects. Likewise you can print projects and its elements.

1.8.1 Minitab Project and Worksheets

Minitab has two main types of files, projects and worksheets. Worksheets are files that are made up of data; think of a spread sheet containing variables of data. Projects are made up of the commands, graphs and worksheets. Every time you save a Minitab project you will be saving graphs, worksheets and commands. However each one of the elements can be saved individually for use in other documents or Minitab projects. Likewise you can print projects and its elements.

The Menu bar: You can open menus and choose commands. Here you can find the built-in routines.

The Toolbar: Shortcuts to some Minitab commands.

1.8.2   Two windows in MINITAB

1.Session Window: The area that displays the statistical results of your data analysis and can also be used to enter commands.

2.Worksheet Window: A grid of rows and columns used to enter and manipulate the data.   Note: This area looks like a spreadsheet but will not automatically update the columns when entries are changed.

Other windows include

- **Graph Window:**   When you generate graphs, each graph is opened in its own window.

- **Report Window:**   Version 13 has a report manager that helps you organize your results in a report.

- **Other Windows:**   History and Project Manager are other windows.   See Minitab help for more information on these if needed
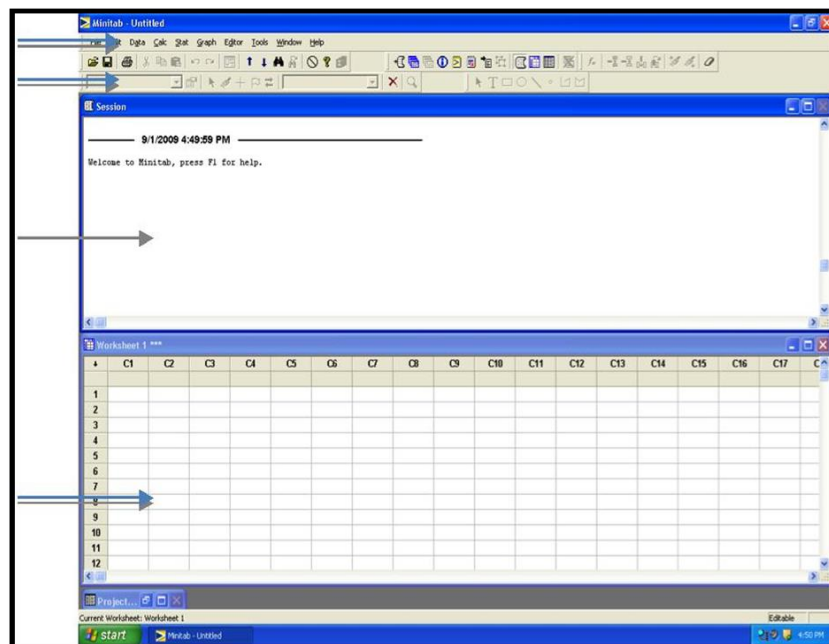
Fig 1.10: Environment in Minitab Software

CHAPTER 2
LITERATURE REVIEW

Maheswari Patil(2012): This paper presents a survey on variation in tool geometry that is tool nose radius, rake angle, variable edge geometry and their effect on tool wear and cutting edge integrity in the turning operation of components from EN9 (C45) plain carbon steel. Heat generated during turning is also affected by edge preparation due to change in work material flow around the cutting edge. The result then obtained will be further useful in selecting appropriate rake angle and nose radius for various conditions of speed, feed and depth of cut further leading to economical machining and improved productivity.

S. Thamizhmanii (2007): The purpose of this research paper is focused on the analysis of optimum cutting conditions to get lowest surface roughness in turning SCM 440 alloy steel by Taguchi method. Experiment was designed using Taguchi method and 18 experiments were designed by this process and experiments conducted. The results are analyzed using analysis of variance (ANOVA) method. Findings: Taguchi method has shown that the depth of cut has significant role to play in producing lower surface roughness followed by feed. The Cutting speed has lesser role on surface roughness from the tests. The vibrations of the machine tool, tool chattering are the other factors which may contribute poor surface roughness to the results and such factors ignored for analyses.The results obtained by this method will be useful to other researches for similar type of study and may be eye opening for further research on tool vibrations, cutting forces etc

Bharath H S(2017): This paper demonstrates the use of High Carbon High Chromium Steel (HCHC) as a single point cutting tool and also evaluated the properties at high temperature range (2000 C to 4000 C), HCHC tool find its applications in blanking or forming dies and thread rolling dies. The experiment results like hardness, tool force analysis using lathe tool dynamometer and tool life using Taylor's tool life equation are compared with HSS single point tool. The results shows that the forged and heat treated HCHC single point cutting tool performs similar to HSS tool and at high temperature performs better than HSS single point tool with higher tool life.

Leonardo R. SILVA (2008): The purpose of this study is to investigate the influence of cutting speed on cutting forces and surface roughness when dry precision turning AISI 1045 steel using uncoated and coated cemented carbide tools. The results indicated that, in general, the turning force components tend to decrease or remain practically stable as cutting speed increased. The specific cutting force presents a similar behaviour as long as feed rate is kept unaltered. The surface roughness produced by the two cutting tools was significantly affected by cutting speed within the range tested.

B.kareem (2011): In this experiment mild steel turning was carried out on the lathe using selected High Speed Steel (HSS) and High Carbon Steel (HCS) single point cutting tools. Speed, feed, and time of machining were varied accordingly, while running with, and without coolant. Hardness of the cutting tips of the tools was measured using Rockwell hardness tester. The corresponding speed, feed and time of machining were also noted. Turning operation was continued until the tool was totally blunt. At this stage recorded values of hardness, time of machining, feed and speed were modeled using multiple regression technique, with and without cutting fluid. The resulting models were strongly in agreement with the measured values. Therefore, the model is a good predictor of flank wear for the selected tools commonly used in developing countries. The findings showed that wear of the cutting tools can be predicted during machining at predetermined cutting conditions.

Raviraj Shetty (2008): This paper discusses the use of Taguchi and response surface methodologies for minimizing the surface roughness in turning of discontinuously reinforced aluminum composites (DRACs) having aluminum alloy 6061 as the matrix and containing 15 vol. % of silicon carbide particles of mean diameter 25µm under pressured steam jet approach. The measured results were then collected and analyzed with the help of the commercial software package MINITAB15. A second-order model has been established between the cutting parameters and surface roughness using response surface methodology. The experimental results reveal that the most significant machining parameter for surface roughness is steam pressure followed by feed. The predicted values and measured values are fairly close, which indicates that the developed model can be effectively used to predict the surface roughness in the machining of DRACs.

K.G Sathisha(2016): This paper is to study the effect of machining parameters like spindle speed, feed rate and depth of cut under the dry and wet machining condition. The experiment was conducted in centre lathe for different machining conditions with dry and two types of cutting fluids. For the experimentation the machining is done with two cutting tool (HSS and Carbide tip tool) with mild steel (AISI 1018) as working material. The selection of proper machining parameters with proper cutting fluids will increase the tool life and will result in good surface finish on the material. Hence the temperature of tool tip -work piece interface was examined at different spindle speed, feed rate and depth of cut with soluble oil and palm oil as cutting fluid. Here in the experiment, an attempt is made to analyse the tool tip temperature at different machining condition by using fluke infrared thermometer with dry and wet machining.

Raviraj Shetty (2008): This paper reports on the experimental investigations carried out under dry, oil water emulsion and steam lubricated conditions in turning of DRACs. The measured results were then collected and analyzed with the help of the commercial software package MINITAB15. The experiments were planned on orthogonal arrays, made with prefixed cutting parameters and different lubricated conditions. An analysis of variance (ANOVA) was carried out to check the validity of the proposed parameters and also their percentage contributions. The results of the tests show that with proper selection of the range of cutting parameters, it is possible to obtain better performance under steam lubricated condition.

CHAPTER3

DESIGN OF EXPERIMENTS

3.1 Design of Experiments (DOE) Overview

In industry, designed experiments can be used to systematically investigate the process or product variables that influence product quality. After identifying the process conditions and product components that influence product quality, direct improvement efforts enhance a product's manufacturability, reliability, quality, and field performance. As the resources are limited, it is very important to get the most information from each experiment performed. Well designed experiments can produce significantly more information and often require fewer runs than haphazard or unplanned experiments. A well-designed experiment identifies the effects that are important. If there is an interaction between two input variables

They should be included in design rather than doing a "one factor at a time" experiment. An interaction occurs when the effect of one input variable is influenced by the level of another input variable.

Designed experiments are often carried out in four phases: planning, screening (also called process characterization), optimization, and verification.

3.1.1 Planning

Careful planning help in avoiding the problems that can occur during the execution of the experimental plan. For example, personnel, equipment availability, funding, and the mechanical aspects of system may affect the ability to complete the experiment. The preparation required before beginning experimentation depends on the problem. Here are some steps need to go through:

• **Define the problem.** Developing a good problem statement helps in studying the right variables.

• **Define the objective.** A well-defined objective will ensure that the experiment answers the right questions and yields practical, usable information. At this step, define the goals of the experiment.

• **Develop an experimental plan that will provide meaningful information.** Review relevant background information, such as theoretical principles, and knowledge gained through observation or previous experimentation.

• **Make sure the process and measurement systems are in control.** Ideally, both the process and the measurements should be in statistical control as measured by a functioning statistical process control (SPC) system. Minitab provides numerous tools to evaluate process control and analyze your measurement system.

3.1.2 Screening

In many process development and manufacturing applications, potentially influential variables are numerous. Screening reduces the number of variables by identifying the key variables that affect product quality. This reduction allows focusing process improvement efforts on the really important variables. Screening suggests the "best" optimal settings for these factors.

The following methods are often used for screening:

• Two-level full and fractional factorial designs are used extensively in industry

• Plackett-Burman designs have low resolution, but they are useful in some screening experimentation and robustness testing.

• General full factorial designs (designs with more than two-levels) may also be useful for small screening experiments.

3.1.3 Optimization

After identifying the vital variables by screening, there is need to determine the "best" or optimal values for these experimental factors. Optimal factor values depend on the process objective.

The optimization methods available in Minitab include general full factorial designs (designs with more than two-levels), response surface designs, mixture designs, and Taguchi designs.

• Factorial Designs Overview describes methods for designing and analyzing general full factorial designs.

• Response Surface Designs Overview describes methods for designing and analyzing central composite and Box-Behnken designs.

• Mixture Designs Overview describes methods for designing and analyzing simplex centroid, simplex lattice, and extreme vertices designs. Mixture designs are a special class of response surface designs where the proportions of the components (factors), rather than their magnitude, are important.

• Response Optimization describes methods for optimizing multiple responses. Minitab provides numerical optimization, an interactive graph, and an overlaid contour plot to help to determine the "best" settings to simultaneously optimize multiple responses.

• Taguchi Designs Overview describes methods for analyzing Taguchi designs. Taguchi designs may also be called orthogonal array designs, robust designs, or inner-outer array designs. These designs are used for creating products that are robust to conditions in their expected operating environment.

3.1.4 Verification

Verification involves performing a follow-up experiment at the predicted "best" processing conditions to confirm the optimization results.

3.2 Advantages & Disadvantages of DOE

DOE became a more widely used modelling 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 behaviour. However, when it comes to nonlinear behaviour, DOE does not always give the best results.

3.3 Factorial Designs

3.3(a) Factorial Designs Overview

Factorial designs allow for the simultaneous study of the effects that several factors may have on a process. When performing an experiment, varying the levels of the factors

simultaneously rather than one at a time is efficient in terms of time and cost, and also allows for the study of interactions between the factors. Interactions are the driving force in many processes. Without the use of factorial experiments, important interactions may remain undetected.

3.3(b) Screening designs

In many process development and manufacturing applications, the number of potential input variables (factors) is large. Screening (process characterization) is used to reduce the number of input variables by identifying the key input variables or process conditions that affect product quality. This reduction allows focusing process improvement efforts on the few really important variables. Screening may also suggest the "best" or optimal settings for these factors. Optimization experiments can then be done to determine the best settings. In industry, two-level full and fractional factorial designs, and Plackett-Burman designs are often used to "screen" for the really important factors that influence process output measures or product quality. General full factorial designs (designs with more than two-levels) may be used with small screening experiments.

3.3.1 Full factorial designs

In a full factorial experiment, responses are measured at all combinations of the experimental factor levels. The combinations of factor levels represent the conditions at which responses will be measured. Each experimental condition is called a "run" and the response measurement an observation. The entire set of runs is the "design."

3.3.1(a) Two level full factorial designs

In a two-level full factorial design, each experimental factor has only two levels. The experimental runs include all combinations of these factor levels. Although two-level factorial designs are unable to explore fully a wide region in the factor space, they provide useful information for relatively few runs per factor. Because two-level factorials can indicate major trends, which are used to provide direction for further experimentation.

3.3.1(b) General full factorial designs

In a general full factorial design, the experimental factors can have any number of levels. For example, Factor A may have two levels, Factor B may have three levels, and Factor C

may have five levels. The experimental runs include all combinations of these factor levels. General full factorial designs may be used with small screening experiments, or in optimization experiments.

3.3.2 Fractional factorial designs

In a full factorial experiment, responses are measured at all combinations of the factor levels, which may result in a prohibitive number of runs. For example, a two-level full factorial design with 6 factors requires 64 runs; a design with 9 factors requires 512 runs. To minimize time and cost, can use designs that exclude some of the factor level combinations. Factorial designs in which one or more level combinations are excluded are called **fractional factorial designs**. Minitab generates two-level fractional factorial designs for up to 15 factors.

Fractional factorial designs are useful in factor screening because they reduce down the number of runs to a manageable size. The runs that are performed are a selected subset or fraction of the full factorial design.

3.3.3 Plackett-Burman designs

Plackett-Burman designs are a class of resolution III, two-level fractional factorial designs that are often used to study the main effects. In a resolution III design, main effects are aliased with two-way interactions. Minitab generates designs for up to 47 factors. Each design is based on the number of runs, from 12 to 48, and is always a multiple of 4. The number of factors must be less than the number of runs.

3.4 Choosing a Factorial Design

The design, or layout, provides the specifications for each experimental run. It includes the blocking scheme, randomization, replication, and factor level combinations. This information defines the experimental conditions for each test run. While performing the experiment, need to measure the response (observation) at the predetermined settings of the experimental conditions. Each experimental condition that is employed to obtain a response measurement is a run. Minitab provides two-level full and fractional factorial designs, Plackett-Burman designs, and full factorials for designs with more than two levels. While choosing a design there is need to

• identify the number of factors that are of interest.

• determine the number of runs you can perform Factorial Designs.

• determine the impact that other considerations (such as cost, time, or the availability of facilities) have on the choice of a design.

3.5 Design of Experiments

3.5.1 Creating Full Factorial Designs

Use Minitab's general full factorial design option when any factor has more than two levels. Using this can create designs with up to 15 factors. Each factor must have at least two levels, but not more than 100 levels.

To create a general full factorial design

1 Choose **Stat > DOE > Factorial > Create Factorial Design**.

2 Choose **General full factorial designs**.

3 From **Number of factors**, choose a number from 2 to 15.

4 Click **Designs**.

5 Click in **Number of Levels** in the row for Factor A and enter a number from 2 to 100. Use the arrow key to move down

The column and specify the number of levels for each factor

6 Click **OK**. This selects the design and brings back to the main dialog box.

7 click **Options** or **Factors** and use any of the dialog box options, then click **OK** to create the design.

Factorial Design − Available Designs

Stat > DOE > Factorial > Create Factorial Design >*choose* **General full factorial design > Display Available Designs**

This dialog box does not take any input.

Factorial Design − Designs

Stat > DOE > Factorial > Create Factorial Design >*choose General full factorial design* **> Design**

Allows naming factors, specifying the number of levels for each factor, adding replicates, and blocking the design.

Dialog box items

Factor: Shows the number of factors that are chosen for the design. This column does not take any input.

Name: Enter text to change the name of the factors. By default, Minitab names the factors alphabetically.

Number of Levels: Enter a number from 2 to 100 for each factor. Use the arrow keys to move up or down the column.

Number of replicates: Enter a number up to 50.

Block on replicates: Check to block the design on replicates. Each set of replicate points will be placed in a separate block.

Factorial Design − Factors

Stat > DOE > Factorial > Create Factorial Design >_choose General full factorial design_ **> Designs > Factors**

Allows naming or renaming the factors and assigning values for factor levels. If factors are continuous, use numeric levels; if factors are categorical, use text levels. Continuous variables can take on any value on the measurement scale being used (for example, length of reaction time). In contrast, categorical variables can only assume a limited number of possible values (for example, type of catalyst).

Use the arrow keys to navigate within the table, moving across rows or down columns.

3.5.2 Dialog box items

Factor: Shows the number of factors is chosen for design. This column does not take any input.

Name: Enter text to change the name of the factors.

Type: Choose to specify whether the levels of the factors are numeric or text.

Levels: Shows the number of levels for each factor. This column does not take any input.

Level Values: Enter numeric or text values for each level of the factor. can have up to 100 levels for each factor.

To name factors

1 In the Create Factorial Design dialog box, click **Factors**.

2 Under **Name**, click in the first row and type the name of the first factor. Then, use the arrow key to move down the column and enter the remaining factor names.

To assign factor levels

1 In the Create Factorial Design dialog box, click **Factors**.

2 Under **Level Values** click in the factor row to assign values and enter any numeric or text value. Enter numeric levels from lowest to highest.

3 Use the arrow key to move down the column and assign levels for the remaining factors. Click **OK**.

3.5.3 Create Design − Options

Stat > DOE > Factorial > Create Factorial Design >_choose General full factorial design_ > **Options**

Allows to randomize the design, and store the design (and design object) in the worksheet.

Dialog box items

Randomize runs: Check to randomize the runs in the data matrix. If blocks are specified, randomization is done separately within each block and then the blocks are randomized.

Base for random data generator: Enter a base for the random data generator. By entering a base for the random data generator, can control the randomization so that can obtain the same pattern every time.
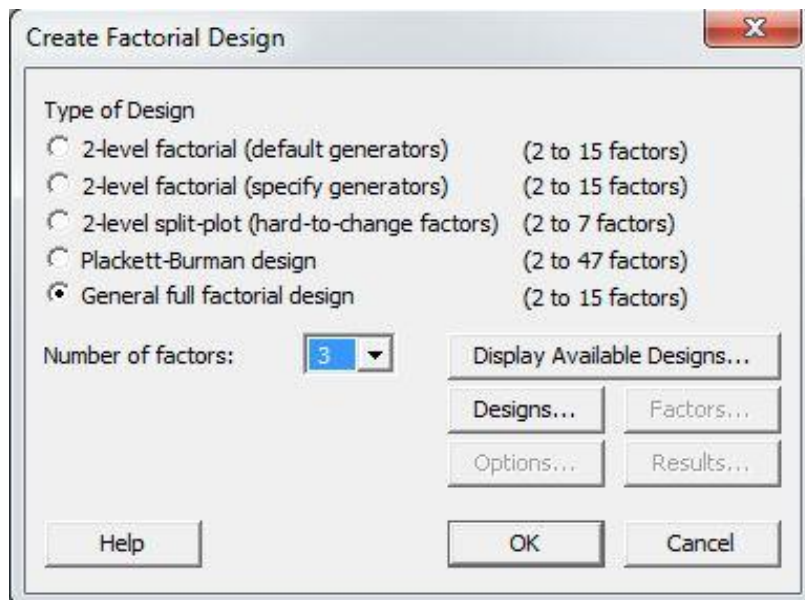
Fig 3.1:Creating factorial Design

3.6 Design of Experiments in Coded form for HCS

sno	speed	feed	d.o.c
1	1	0	1
2	0	-1	-1
3	1	-1	1
4	1	0	0
5	-1	1	-1
6	0	-1	0
7	-1	-1	-1
8	1	0	-1
9	1	-1	-1
10	-1	-1	1
11	-1	0	-1
12	-1	0	1
13	1	-1	0
14	-1	1	1
15	-1	1	0
16	1	1	0
17	-1	0	0
18	0	0	-1
19	1	1	1
20	0	0	0
21	0	-1	1
22	0	1	1
23	1	1	-1
24	0	1	0
25	-1	-1	0
26	0	0	1
27	0	1	-1

Table 3.1: Design of Experiments in coded form for HCS

3.7 Design of Experiments in Coded form for HSS

Sno	speed	feed	d.o.c
1	1	0	-1
2	-1	1	0
3	-1	1	1
4	-1	1	-1
5	1	-1	1
6	-1	0	-1
7	0	-1	-1
8	0	-1	0
9	1	0	0
10	-1	0	1
11	-1	-1	1
12	0	1	-1
13	1	-1	-1
14	1	1	1
15	-1	-1	0
16	0	0	1
17	0	1	1
18	0	1	0
19	0	0	0
20	0	0	-1
21	1	0	1
22	-1	0	0
23	-1	-1	-1
24	1	-1	0
25	0	-1	1
26	1	1	-1
27	1	1	0

Table 3.2: Design of Experiments in coded form for HSS

CHAPTER 4

EXPERIMENTAL SETUP AND MACHINING

The project was done in 3 stages.

- Design of experiments was done using full factorial method.

- Cycle time was calculated by machining the work piece on lathe machine

- Analysis of results was done using MINITAB 17.1.30.

4.1 Selection of process variables

- A total of three process variables and 3 levels are selected for the experimental procedure.

- The deciding process variables are

    - Speed

    - Feed

    - Depth of cut

- Speed of the spindle, i.e. the speed at which the spindle rotates the tool.

- Feed is the rate at which the material is removed from the work piece.

- Depth of cut is the depth up to which the tool is emerged in one cycle.

4.2 Selection of levels:

- Since it is a three level design by observing the parameters taken in various projects the levels of the factors are designed as follows

FACTORS	LEVEL1	LEVEL2	LEVEL3
S.SPEED(RPM)	125	200	300
FEED(MM/REV)	0.5	0.75	1
D.O.C(MM)	0.5	0.75	1

Table 4.1: Selection of process variables

4.3 Design of Experiments

- Design of experiments was done using full factorial method.

- Design of experiments (DOE) or experimental design is the design of any information-gathering exercises where variation is present, whether under the full control of the experimenter or not.

4.4 Selection of material

By studying various projects EN 9 is selected for machining operation. The composition of EN 9 is:

- Silicon – 0.05 to 0.3%
- Carbon - 0.5 to 0.60%
- Manganese -0.5 to 0.80%

The dimensions of the workpiece used are length 50mm*16mmdia

4.5 Clamping of the work piece

The work piece is clamped to the machine by using standard 3 jaw chuck.
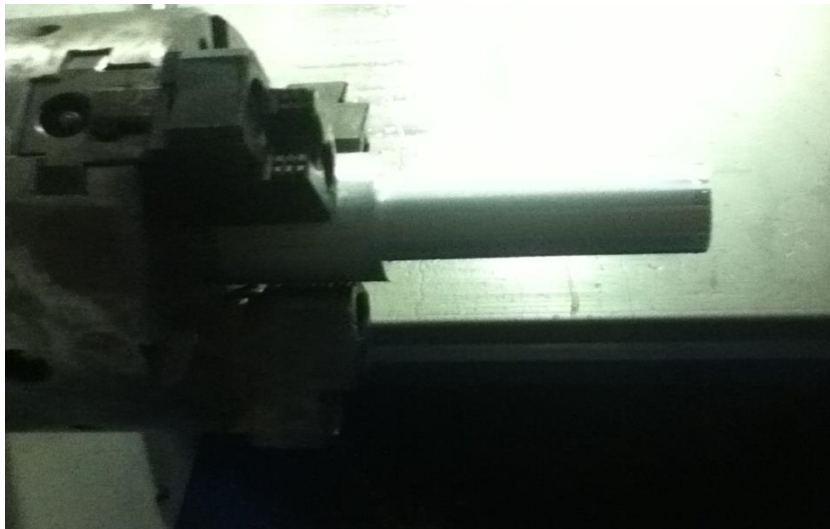
Fig 4.1: Clamping of the work piece

The tool used for turning is High Speed Steel. Initially these tool is fixed in the tool turret using tool holding fixture.

4.6 Material Removal Rate

Machining speed(mm/min) = feed(mm/rev) * r.p.m(rev/min)

Machining time(min) = length of the specimen / machining speed

MRR(material removal rate) =

$$(\text{final weight} - \text{initial weight})/ (\text{density} * \text{machining time})$$

4.6.1 Sample calculation

Feed = 1 mm/rev

Speed = 300   rpm

length of specimen = 50mm

 initial weight = 251kg

final weight = 232 kg

Density of specimen= 8080 kg/m^3

Machining speed = 1* 300 = 300 mm/min

Machining time = 50*60/300 = 10sec

MRR = (251-232)/(8080*10) = 2.103 * 10^-4

CHAPTER 5
ANALYSIS OF VARIANCE

5.1 ANALYSIS OF VARIANCE (ANOVA) USING MINITAB

ANOVA was developed by the English statistician, R.A. Fisher (1890-1962). Though initially dealing with agricultural data, this methodology has been applied to a vast array of other fields for data analysis. Despite its widespread use, some practitioners fail to recognize the need to check the validity of several key assumptions before applying an ANOVA to their data. It is the hope that this article may provide certain useful guidelines for performing basic analysis using such a software package.

Analysis of variance (ANOVA) is a collection of statistical models used to analyze the differences between group means and their associated procedures (such as "variation" among and between groups), in which the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether or not the means of several groups are all equal, and therefore generalizes t-test to more than two groups. Doing multiple two-sample t-tests would result in an increased chance of committing a type I error. For this reason, ANOVAs are useful in comparing (testing) three, or more means (groups or variables) for statistical significance.

ANOVA is a particular form of statistical hypothesis testing heavily used in the analysis of experimental data. A statistical hypothesis test is a method of making decisions using data. A test result (calculated from the null hypothesis and the sample) is called statistically significant if it is deemed unlikely to have occurred by chance, assuming the truth of the null hypothesis. A statistically significant result (when a probability (p-value) is less than a threshold (significance level)) justifies the rejection of the null hypothesis.

The terminology of ANOVA is largely from the statistical design of experiments. The experimenter adjusts factors and measures responses in an attempt to determine an effect. Factors are assigned to experimental units by a combination of randomization and blocking to ensure the validity of the results. Blinding keeps the weighing impartial. Responses show a variability that is partially the result of the effect and is partially random error. ANOVA is the synthesis of several ideas and it is used for multiple purposes. As a consequence, it is difficult to define concisely or precisely.

5.2 Characteristics of ANOVA

ANOVA is used in the analysis of comparative experiments, those in which only the difference in outcomes is of interest. The statistical significance of the experiment is determined by a ratio of two variances. This ratio is independent of several possible alterations to the experimental observations: Adding a constant to all observations does not alter significance. Multiplying all observations by a constant does not alter significance. So ANOVA statistical significance results are independent of constant bias and scaling errors as well as the units used in expressing observations. In the era of mechanical calculation it was common to subtract a constant from all observations (when equivalent to dropping leading digits) to simplify data entry. This is an example of data coding.

Classical ANOVA for balanced data does three things at once:

1. As exploratory data analysis, an ANOVA is an organization of additive data decomposition, and its sums of squares indicate the variance of each component of the decomposition (or, equivalently, each set of terms of a linear model).

2. Comparisons of mean squares, along with F-tests ... allow testing of a nested sequence of models.

3. Closely related to the ANOVA is a linear model fit with coefficient estimates and standard errors.

In short, ANOVA is a statistical tool used in several ways to develop and confirm an explanation for the observed data.

Additionally:

It is computationally elegant and relatively robust against violations to its assumptions.

4. ANOVA provides industrial strength (multiple sample comparison) statistically.

5. It has been adapted to the analysis of a variety of experimental designs.

5.3 Analysis of variance using Factorial method

The purpose of this handout is to assist the burgeoning statistician in analysing and interpreting the meaning of a statistically significant interaction in the context of factorial analysis of variance (ANOVA). We shall assume that the reader is already familiar with the results obtained when factorial ANOVA is the chosen analytic technique. However, just to be on the safe side, we will review the basics as we go through two examples demonstrating two of the methods that can be used as a follow-up to a statistically

significant interaction effect. The two approaches that we will discuss are: 1. tests of simple main effects, and 2. statistical comparison of cell s

Steps involved in Factorial method

Step 1: Create design using General factorial method

Stat – DOE – Factorial – Create Factorial design
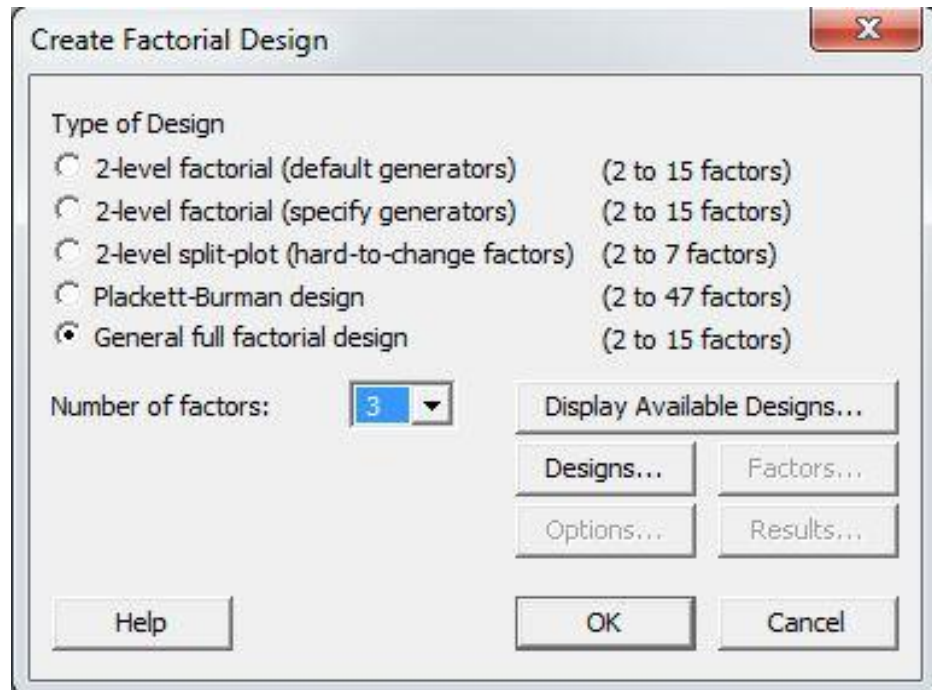

Fig 5.1: Factorial design model

Step 2: Define Response Surface Design by selecting Speed, Feed, and Depth of cut as Input parameters.

Stat – DOE – Factorial – Define Response Surface Design
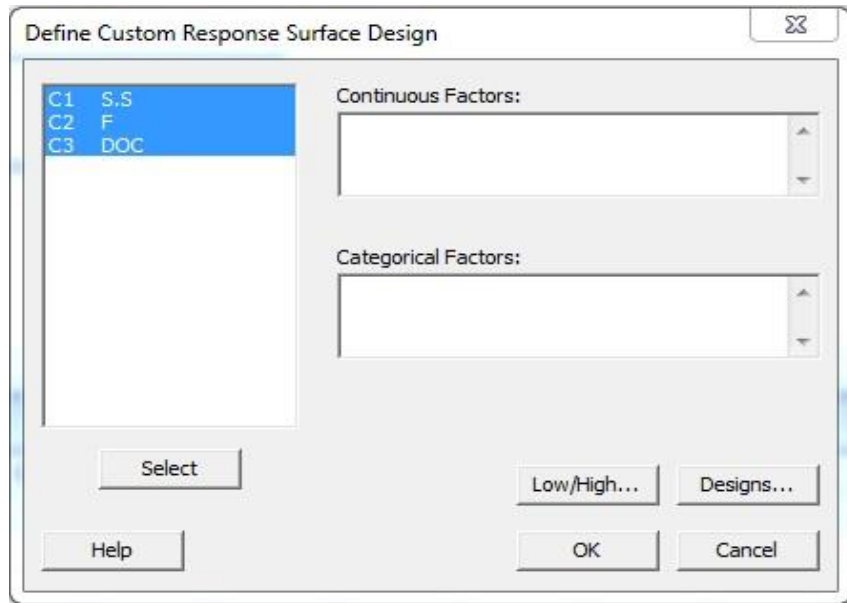
Fig 5.2: Custom Response Surface Design

Step 3: Analyse the Custom Response design

Stat – DOE – Response Surface – Analyse Response Design
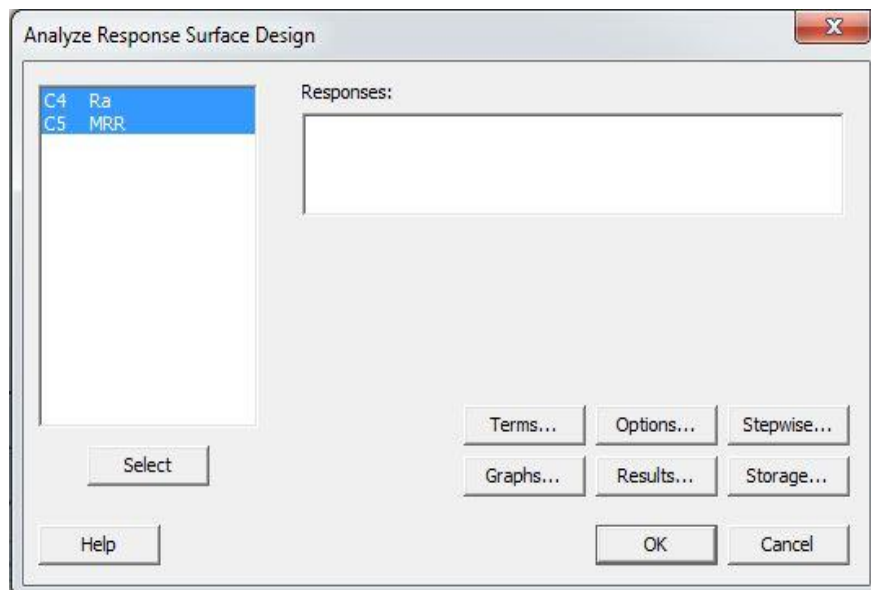
Fig 5.3: Analyse Response Surface Design

CHAPTER-6

RESULTS AND DISCUSSIONS

6.1 Development of Mathematical Models

A Second -order polynomial is employed for developing the mathematical model for predicting weld pool geometry. If the response is well modelled by a linear function of the independent variables then the approximating function is the first order model as shown in Equation.

$$\mathbf{Y} = \boldsymbol{\beta} + \boldsymbol{\beta}_1 \mathbf{x}_1 + \boldsymbol{\beta}_2 \mathbf{x}_2 + \dots\_ \boldsymbol{\beta}_x \mathbf{x}_x + \in$$

A mathematical regression equation is developed for cycle time in every tool path and the graphs are plotted.

$$\mathbf{Y} = \boldsymbol{\beta}_0 + \sum_{i=1}^{k} \boldsymbol{\beta}_o x_o + \sum_{i=1}^{k} \boldsymbol{\beta}_{ii}\, x_{i2} + \sum \quad \sum_{i<j} \boldsymbol{\beta}_{ij}\, x_i x_j + \mathbf{\in}$$

- Y is the corresponding response
- X_i are the cutting parameters
- (1,2,…….k) are code levels of quantitative process variables
- The terms are the second order regression coefficients

- Second term is attribute to linear effect
- Third term corresponds to higher order effects
- Fourth term includes the interactive effects of the process parameters.
- And the last term indicates the experimental error.

- All the 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.

6.2 Different Terms used in Response Surface Methodology Regression table

1. P-values: P- Values (P) are used to determine which of the effects in the model are statistically significant.

- If the p-value is less than or equal to 0.5, conclude that the effect is significant.
- If the p-value is greater than 0.5, conclude that the effect is not significant.

2. **Coefficients**: Coefficients are used to construct an equation representing the relationship between the response and the factors.

3. R-squared: R and adjusted R represent the proportion of variation in the response that is explained by the model.

- R (R-Sq) describes the amount of variation in the observed responses that is explained by the model.
- Predicted R reflects how well the model will predict future data.
- Adjusted R is a modified R that has been adjusted for the number of terms in the model. If we include unnecessary terms, R can be artificially high. Unlike R , adjusted R may get smaller when we add terms to the model.

4. Analysis of variance table*:* P-values (P) are used in analysis of variance table to determine which of the effects in the model are statistically significant. The interaction effects in the model are observed first because a significant interaction will influence the main effects.

5.Estimated coefficients using uncoded units

- Minitab displays the coefficients in uncoded units in addition to coded units if the two units differ.
- For each term in the model, there is a coefficient. These coefficients are useful to construct an equation representing the relationship between the response and the factors.

6.3 Graphs Obtained

6.3.1 Contour Plots

- Contour and surface plots are useful for establishing desirable response values and operating conditions.
- A contour plot provides a two-dimensional view where all points that have the same response are connected to
- Produce contour lines of constant responses.
- A surface plot provides a three-dimensional view that may provide a clearer picture of the response surface.

Contour/Surface Plots − Contour – Setup

Stat > DOE > Factorial > Contour/Surface Plots >check Contour > Setup

- Generates a response surface contour plot for a single pair of factors or separate contour plots for all possible pairs of factors.
- Contour plots shows that as the lines are diverging towards spindle speed and feed, these two parameters have vital effect on machining process.
- A main effect occurs when the mean response changes across the levels of a factor main effect plots are used to compare the relative strength of the effects across factors.

6.3.1 OBSERVATION TABLE FOR HCS

sno	speed	Feed	Depth of cut	Temperature	Cutting forces		MRR(*10^-4)
28	300	1	1	40	49	70	2.103
29	300	1	0.75	36.6	38	75	1.7326
30	300	1	0.5	34	22	65	1.1138
31	300	0.75	1	41.2	55	83	1.3926
32	300	0.75	0.75	41	37	79	1.299
33	300	0.75	0.5	39	36	82	1.114
34	300	0.5	1	40	44	71	1.237
35	300	0.5	0.75	37	32	64	1.1138
36	300	0.5	0.5	37.1	39	68	1.051
37	200	1	1	39	53	95	1.155
38	200	1	0.75	38	47	86	0.99
39	200	1	0.5	37	40	93	0.907

40	200	0.75	1	39	57	92	0.1051
41	200	0.75	0.75	44.6	49	95	0.928
42	200	0.75	0.5	41	48	98	0.866
43	200	0.5	1	44.6	58	100	0.82508
44	200	0.5	0.75	44	48	95	0.7838
45	200	0.5	0.5	42	37	68	0.701
46	125	1	1	46	69	99	0.8766
47	125	1	0.75	44	64	100	0.773
48	125	1	0.5	43	60	92	0.721
49	125	0.75	1	42	59	97	0.812
50	125	0.75	0.75	41	66	90	0.7735
51	125	0.75	0.5	39	54	94	0.734
52	125	0.5	1	38	65	84	0.6188
53	125	0.5	0.75	36	55	92	0.593
54	125	0.5	0.5	34	49	79	0.5072

Table 6.1:Observations for HCS Cutting tool

6.4 HCS WET CONDTION RESULTS

6.4.1 Response Surface Regression: MRR versus Speed, Feed, Depth of cut

```
Model Summary

        S    R-sq  R-sq(adj)  R-sq(pred)
0.221907  78.66%    67.36%      49.45%


Coded Coefficients


Term            Coef    SE Coef    T-Value    P-Value
Constant        0.826   0.114       7.23       0.000
speed           0.3193  0.0523      6.11       0.000
Feed            0.1671  0.0524      3.19       0.005
d.o.c           0.0832  0.0524      1.59       0.131
speed*speed     0.1828  0.0928      1.97       0.065
Feed*Feed       0.0975  0.0906      1.08       0.297
d.o.c*d.o.c    -0.0630  0.0906     -0.69       0.496
speed*Feed      0.0770  0.0638      1.21       0.244
speed*d.o.c     0.1019  0.0638      1.60       0.129
Feed*d.o.c      0.0809  0.0641      1.26       0.224



Regression Equation in Uncoded Units


mrr=2.72-0.01263*s-3.39*F-0.12*d.o.c+0.000024*s*s
+1.56*F*F+1.01*d.o.c*d.o.c+0.00352*s*F+0.00466*s*d.o.c+1.29*
F*d.o.c
```

6.4.2 Response Surface Regression: Fx versus Speed, Feed, Doc

```
Model Summary


      S    R-sq  R-sq(adj)  R-sq(pred)
5.01532  87.62%    81.07%      64.18%
```

Coded Coefficients

Term	Coef	SE Coef	T-Value	P-Value
Constant	48.15	2.58	18.64	0.000
speed	-10.50	1.18	-8.88	0.000
Feed	0.72	1.18	0.61	0.551
d.o.c	6.97	1.18	5.89	0.000
speed*speed	2.61	2.10	1.24	0.230
Feed*Feed	-2.94	2.05	-1.44	0.169
d.o.c*d.o.c	1.22	2.05	0.60	0.558
speed*Feed	-2.39	1.44	-1.66	0.116
speed*d.o.c	1.72	1.44	1.19	0.250
Feed*d.o.c	0.58	1.45	0.40	0.692

Regression Equation in Uncoded Units

```
fx = 50.8 - 0.242*s + 89.7*F - 25.1 d.o.c + 0.000341*s*s -
 47.1*F*F+ 19.6*d.o.c*d.o.c    - 0.1092*s*F+ 0.0786*s*d.o.c
+ 9.3*F*d.o.c
```

6.4.3 Response Surface Regression: Fy versus Speed, Feed, Depth of cut

```
Analysis of Variance for Fy

Model Summary
      S    R-sq  R-sq(adj)  R-sq(pred)
6.80420  78.13%    66.55%      47.69%
```

Coded Coefficients

Term	Coef	SE Coef	T-Value	P-Value
Constant	95.55	3.50	27.27	0.000
speed	-9.44	1.60	-5.89	0.000
Feed	2.89	1.61	1.80	0.090
d.o.c	2.86	1.61	1.78	0.093
speed*speed	-7.70	2.85	-2.71	0.015
Feed*Feed	-6.89	2.78	-2.48	0.024
d.o.c*d.o.c	-1.22	2.78	-0.44	0.665
speed*Feed	-2.32	1.96	-1.18	0.253
speed*d.o.c	-0.62	1.96	-0.32	0.754
Feed*d.o.c	-2.17	1.96	-1.10	0.285

Regression Equation in Uncoded Units

```
fy=-58.1+0.420*s+225.4*F+72.8*d.o.c-0.001005*s*s-110.2*F*F-
19.6 d.o.c*d.o.c-0.1059*s*F-0.0285*s*d.o.c -34.7*F*d.o.c
```

6.4.4 Response Surface Regression: Temp versus Speed, Feed, Depth of cut

```
Analysis of Variance for Temp

Model Summary
        S     R-sq  R-sq(adj)  R-sq(pred)
 2.82353   49.73%     23.11%       0.00%

Coded Coefficients

Term              Coef    SE Coef   T-Value   P-Value
Constant          42.17    1.45      29.00     0.000
speed            -0.950    0.666     -1.43     0.172
Feed              0.170    0.667      0.26     0.802
d.o.c             1.324    0.667      1.99     0.063
speed*speed      -1.53     1.18      -1.30     0.211
Feed*Feed        -1.41     1.15      -1.22     0.239
d.o.c*d.o.c      -0.47     1.15      -0.41     0.687
speed*Feed       -2.143    0.812     -2.64     0.017
speed*d.o.c       0.154    0.812      0.19     0.852
Feed*d.o.c        0.125    0.815      0.15     0.880

Regression Equation in Uncoded Units

temperature  =   0.7  + 0.1425*s  + 53.7*F  + 13.6*d.o.c  -
0.000200*s*s- 22.5*F*F    - 7.6 d.o.c*d.o.c    - 0.0980*s*F
+ 0.0070*s*d.o.c+ 2.0*F*d.o.c
```
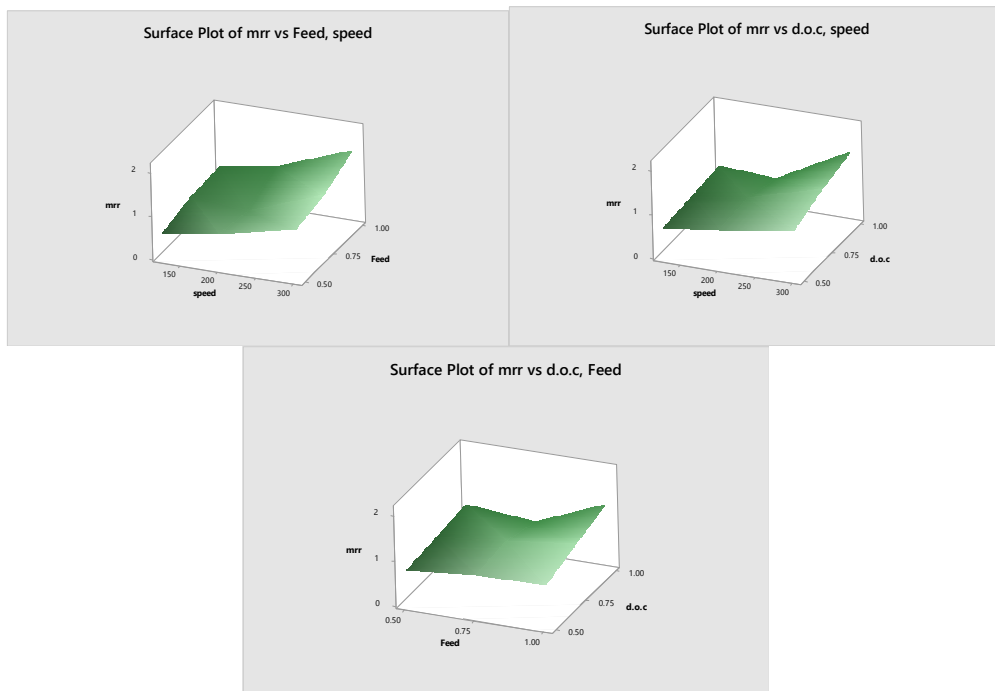
6.4.5 SURFACE PLOT OF MRR

Fig 6.1: Surface Plots for MRR versus speed ,feed ,depth of cut for HCS

6.4.6 CONTOUR PLOT OF MRR
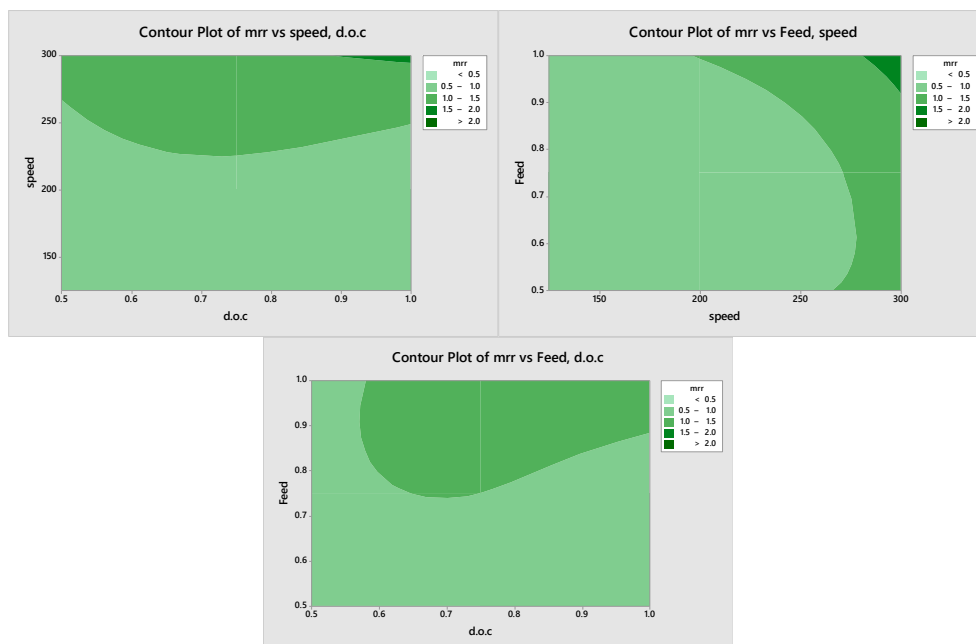

Fig 6.2: Contour Plots for MRR versus speed ,feed ,depth of cut for HCS
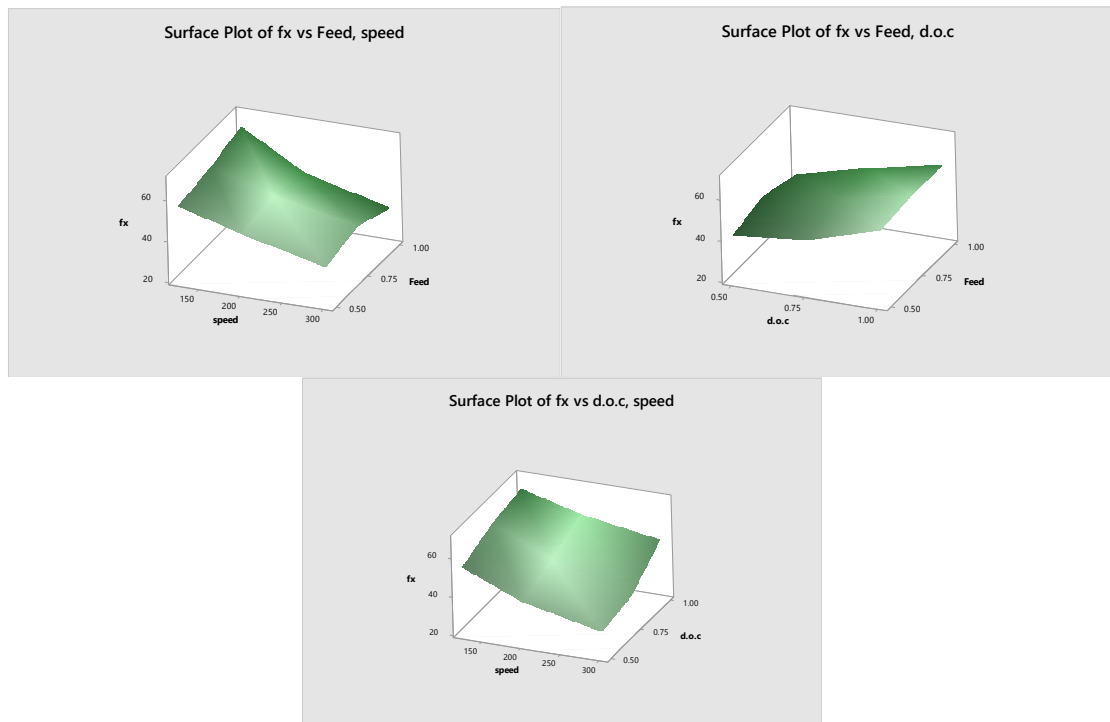
6.4.7 SURFACE PLOT OF FₓX

Fig 6.3:Surface Plots Fₓ versus speed ,feed ,depth of cut for HCS
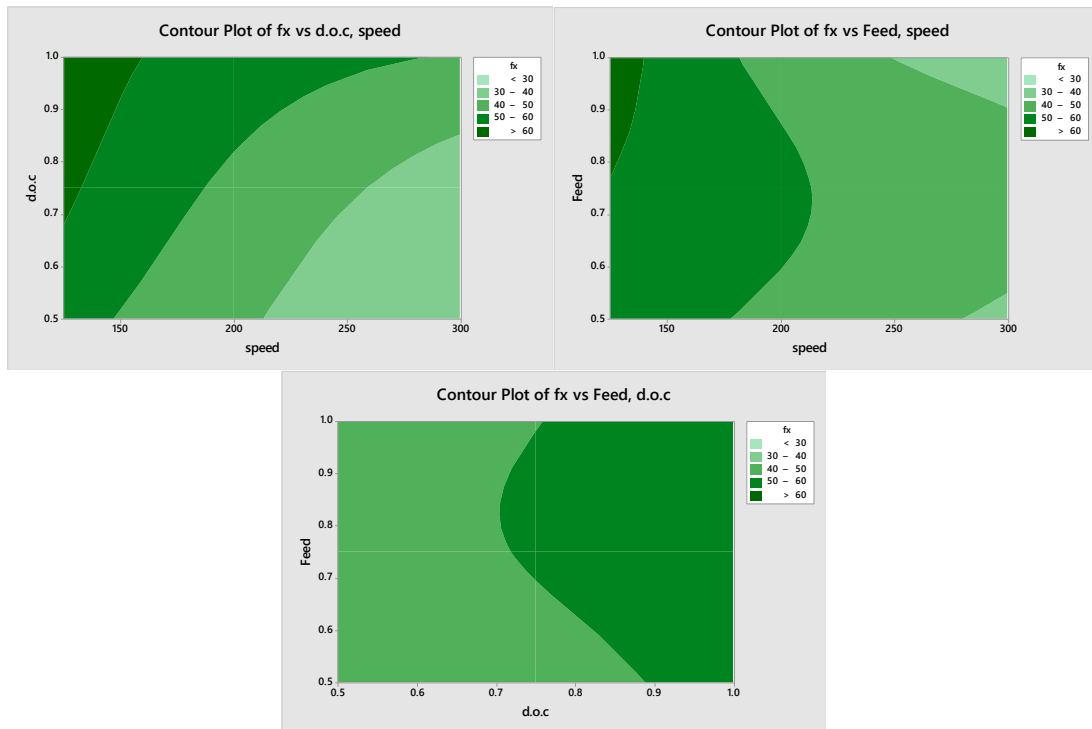
6.4.8 CONTOUR PLOT OF FₓX

Fig 6.4: Contour Plots for Fₓ versus speed ,feed ,depth of cut for HCS
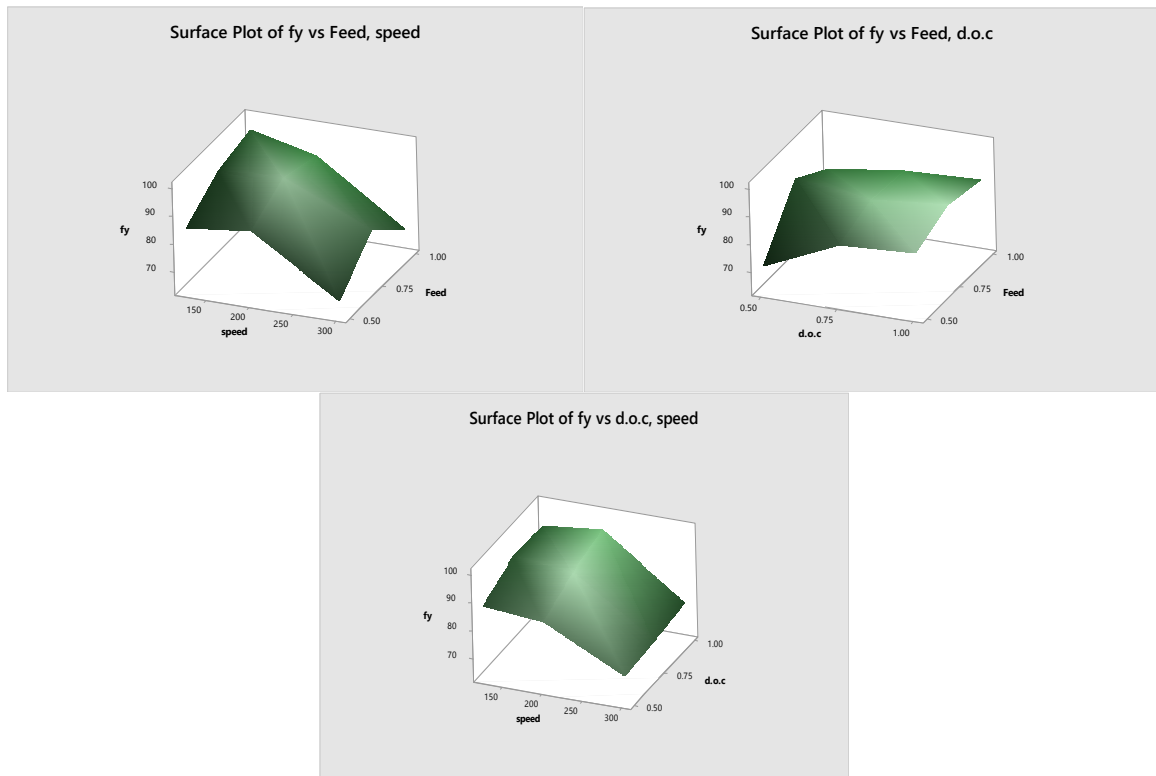
6.4.9 SURFACE PLOT OF F$_Y$

Fig 6.5: Surface Plots for F$_Y$ versus speed ,feed ,depth of cut for HCS
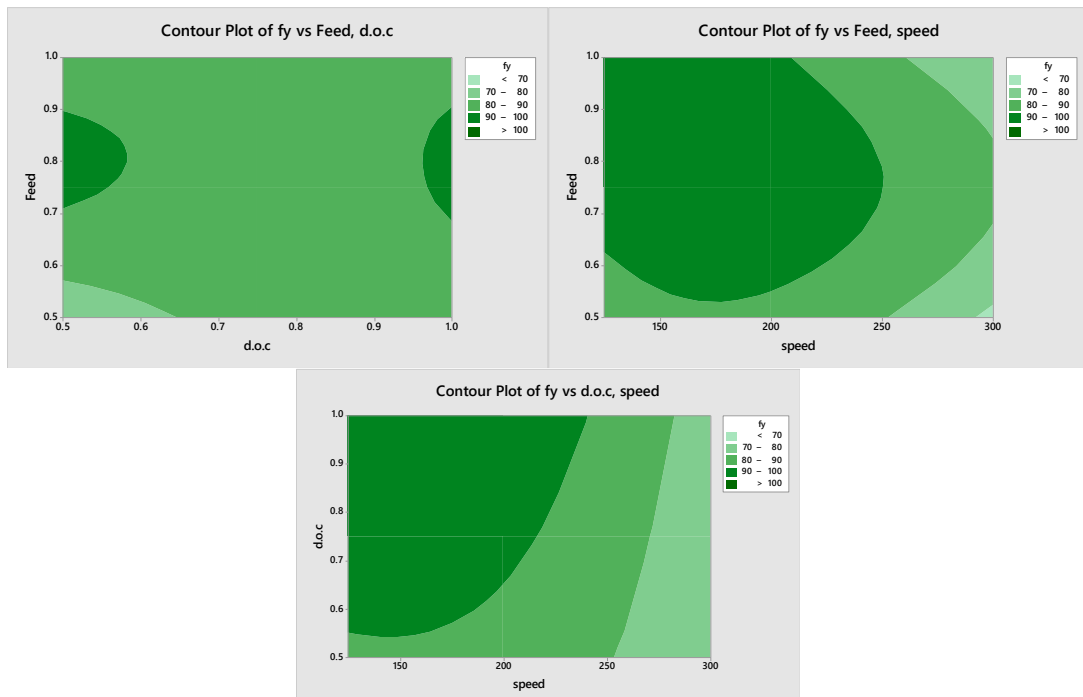
6.4.10 CONTOUR PLOT OF F$_Y$

Fig 6.6: Surface Plots for F$_Y$ versus speed ,feed ,depth of cut for HCS
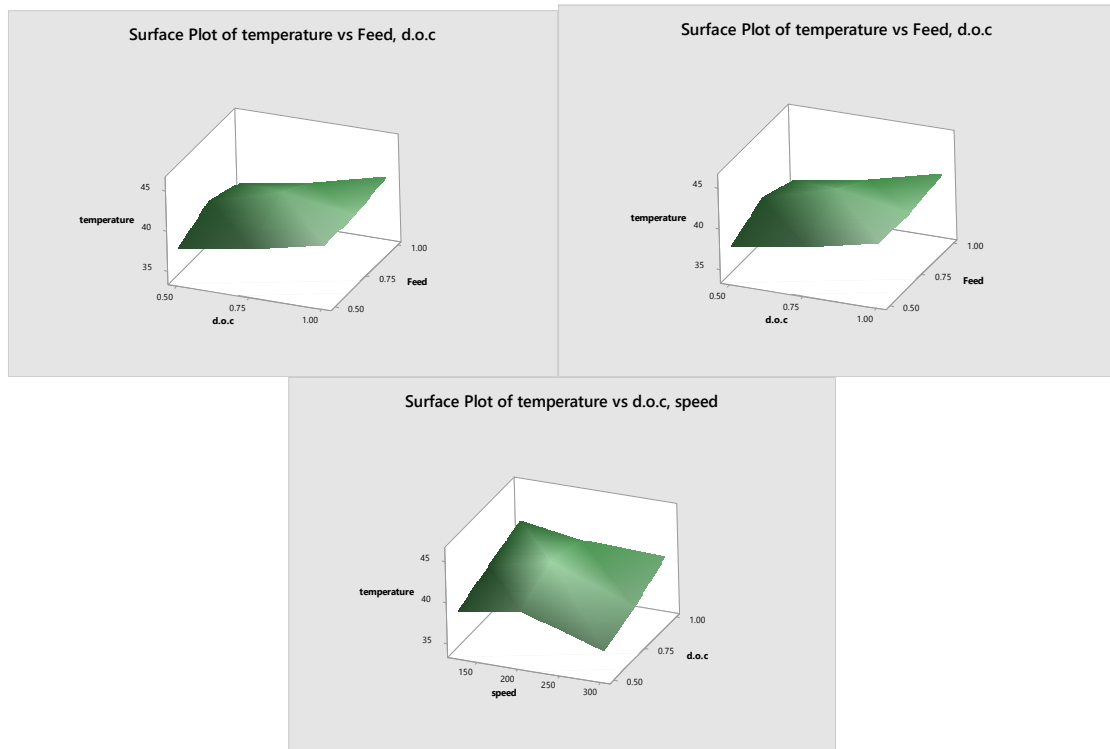
6.4.11 SURFACE PLOT OF TEMPERATURE

Fig 6.7: Surface Plots of Temperature versus speed ,feed ,depth of cut for HCS
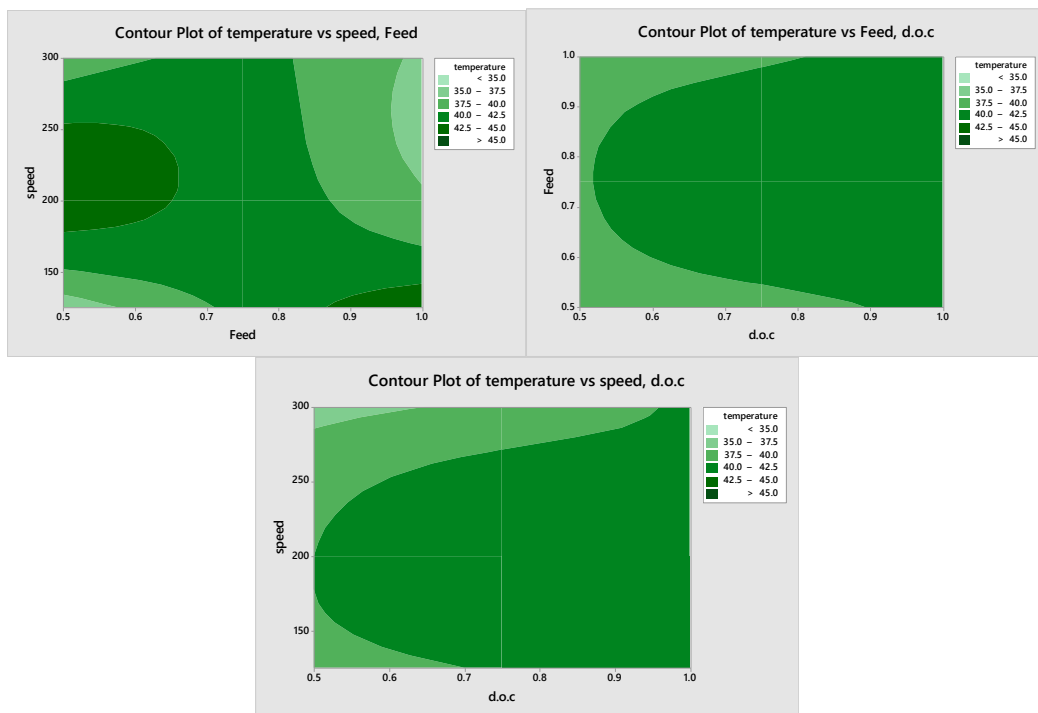
6.4.12 CONTOUR PLOT OF TEMPERATURE

Fig 6.8: Contour Plots for Temperature versus speed ,feed ,depth of cut for HCS

6.5 MULTI RESPONSE OPTIMISATION

6.5.1 RESPONSE OPTIMISATION

```
Response        Goal       Lower   Target   Upper   Weight
mrr             Maximum    0.1051   2.103                   1
fy              Minimum            64.000     100           1
temperature     Minimum            34.000      46           1
fx              Minimum            22.000      69           1

Solution
```

Solution	speed	Feed	d.o.c	mrr Fit	fy Fit	temperature Fit
1	300	1	0.5	1.34027	70.7985	34.2315

```
Multiple Response Prediction
Variable  Setting
speed     300
Feed      1
d.o.c     0.5
```

6.5.2 Response
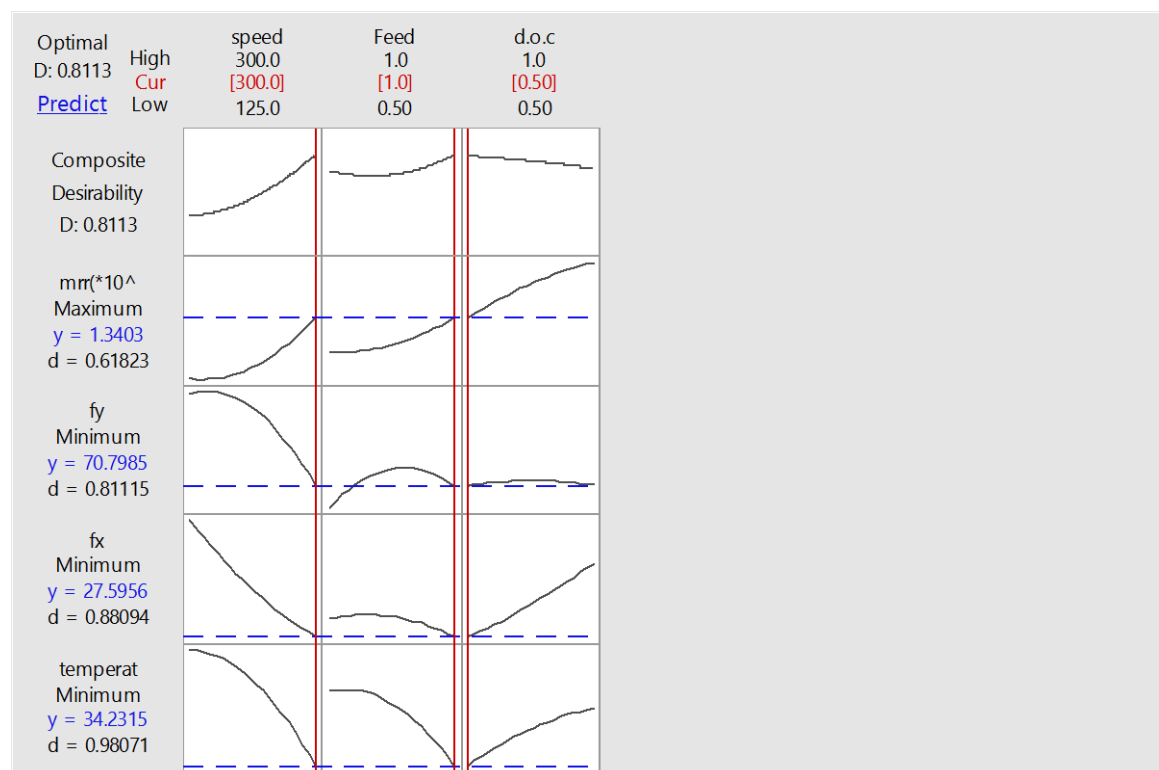

Fig 6.9: Response Optimisation of MRR,F_X,F_Y,Temperature for HCS

6.6 OBSERVATION TABLE FOR HSS

sno	speed(rpm)	Feed(mm/rev)	d.o.c(mm)	temperature(^{o}c)	Cutting forces(N)		MRR(*10^-4)(m³/s)
1	300	1	1	41.4	49	116	1.6089
2	300	1	0.75	37.2	48	113	1.113
3	300	1	0.5	48	30	104	0.866
4	300	0.75	1	123	69	126	1.021
5	300	0.75	0.75	112	41	124	0.742
6	300	0.75	0.5	42.1	50	122	0.6499
7	300	0.5	1	38	37	101	0.6188
8	300	0.5	0.75	44	33	96	0.4331
9	300	0.5	0.5	42	18	85	0.3712
10	200	1	1	52	49	126	1.155
11	200	1	0.75	46	52	130	0.825
12	200	1	0.5	43	39	128	0.66
13	200	0.75	1	53	59	126	0.866
14	200	0.75	0.75	56	47	131	0.6806
15	200	0.75	0.5	43	57	127	0.6188
16	200	0.5	1	43	49	122	0.4837
17	200	0.5	0.75	35.2	22	115	0.33
18	200	0.5	0.5	40	21	109	0.2473
19	125	1	1	39	34	114	0.5672
20	125	1	0.75	39	42	111	0.51567
21	125	1	0.5	42	39	102	0.4641
22	125	0.75	1	38	65	128	0.5801
23	125	0.75	0.75	43	62	115	0.4641
24	125	0.75	0.5	44	52	105	0.4254
25	125	0.5	1	41	41	99	0.36097
26	125	0.5	0.75	35	34	89	0.3351
27	125	0.5	0.5	36	33	84	0.3094

Table 6.2:Observations for HSS Cutting tool

6.7 HSS WET CONDTION RESULTS

6.7.1 Response Surface Regression: MRR versus Speed, Feed, Doc

```
Model Summary

        S     R-sq   R-sq(adj)   R-sq(pred)
0.0699990   96.70%     94.95%       89.82%

Analysis of variance for MRR

Coded Coefficients
```

```
Term             Coef    SE Coef   T-Value  P-Value
Constant        0.6736   0.0360     18.69    0.000
speed           0.1890   0.0165     11.45    0.000
Feed            0.2444   0.0165     14.79    0.000
d.o.c           0.1513   0.0165      9.15    0.000
speed*speed    -0.0438   0.0293     -1.50    0.153
Feed*Feed      -0.0462   0.0286     -1.62    0.124
d.o.c*d.o.c     0.0554   0.0286      1.94    0.069
speed*Feed      0.1326   0.0201      6.58    0.000
speed*d.o.c     0.0860   0.0201      4.27    0.001
Feed*d.o.c      0.0671   0.0202      3.32    0.004
```

Regression Equation in Uncoded Units

$$mrr = 1.048 - 0.00290 \cdot S - 0.007 \cdot F - 2.364 \cdot d.o.c - 0.000006 \cdot s \cdot s - 0.739 \cdot F \cdot F + 0.886 \cdot d.o.c \cdot d.o.c + 0.006061 \cdot s \cdot F + 0.003930 \cdot s \cdot d.o.c + 1.074 \, F \cdot d.o.c$$

6.7.2 Response Surface Regression: F$_x$ versus Speed, Feed, Doc

Analysis of variance for f_x

Model Summary

```
      S     R-sq   R-sq(adj)   R-sq(pred)
7.16037   80.57%    70.29%       54.39%
```

Coded Coefficients

```
Term             Coef    SE Coef   T-Value   P-Value
Constant        54.98     3.69      14.91     0.000
speed           -1.50     1.69      -0.89     0.387
Feed             5.34     1.69       3.16     0.006
d.o.c            6.44     1.69       3.81     0.001
speed*speed     -0.52     2.99      -0.17     0.865
Feed*Feed      -18.56     2.92      -6.35     0.000
d.o.c*d.o.c      1.61     2.92       0.55     0.589
speed*Feed       2.45     2.06       1.19     0.250
speed*d.o.c      3.37     2.06       1.63     0.121
Feed*d.o.c      -2.58     2.07      -1.25     0.228
```

Regression Equation in Uncoded Units

$$fx = -113.1 - 0.188 \cdot s + 473.9 \cdot F - 14.6 \cdot d.o.c - 0.000068 \cdot s \cdot s - 296.9 \cdot F \cdot F + 25.8 \cdot d.o.c \cdot d.o.c + 0.1121 \cdot s \cdot F + 0.1539 \cdot s \cdot d.o.c - 41.3 \cdot F \cdot d.o.c$$

6.7.3 Response Surface Regression: F$_Y$ versus Speed, Feed, Doc

```
Analysis of variance for fy

Model Summary

      S    R-sq  R-sq(adj)  R-sq(pred)
5.47687  90.16%    84.95%      75.74%

Coded Coefficients
```

Term	Coef	SE Coef	T-Value	P-Value
Constant	135.11	2.82	47.91	0.000
speed	2.22	1.29	1.72	0.103
Feed	7.99	1.29	6.18	0.000
d.o.c	5.05	1.29	3.91	0.001
speed*speed	-17.00	2.29	-7.42	0.000
Feed*Feed	-14.67	2.24	-6.56	0.000
d.o.c*d.o.c	-1.33	2.24	-0.60	0.559
speed*Feed	-0.21	1.58	-0.14	0.894
speed*d.o.c	-1.25	1.58	-0.79	0.440
Feed*d.o.c	-1.83	1.58	-1.16	0.262

```
Regression Equation in Uncoded Units

fy = -180.8+1.019*s+408.0*F+86.3*d.o.c- .002220*s*s -
234.7*F*F - 21.3 d.o.c*d.o.c - 0.0097*s*F- 0.0569*s*d.o.c -
 29.3*F*d.o.c
```

6.7.4 Response Surface Regression: Temperature versus Speed, Feed, Doc

```
Analysis of variance for temperature

Model Summary

      S    R-sq  R-sq(adj)  R-sq(pred)
18.7762  46.40%    18.02%      0.00%

Coded Coefficients
```

Term	Coef	SE Coef	T-Value	P-Value
Constant	62.28	9.67	6.44	0.000
Speed	9.48	4.43	2.14	0.047
Feed	1.83	4.43	0.41	0.685
d.o.c	5.20	4.43	1.17	0.257
speed*speed	2.15	7.85	0.27	0.787
Feed*Feed)	-20.36	7.67	-2.66	0.017
d.o.c*d.o.c	-2.57	7.67	-0.34	0.741
speed*Feed	-0.58	5.40	-0.11	0.915
speed*d.o.c	6.24	5.40	1.15	0.264
Feed*d.o.c	-0.38	5.42	-0.07	0.944

```
Regression Equation in Uncoded Units
temp(oc) = -138-0.205*s+506*F + 27*d.o.c+0.00028 s*s -
 326 F*F- 41 d.o.c*d.o.c - 0.027 s*f+ 0.285 s*d.o.c -
6.1 Feed*d.o.c
```
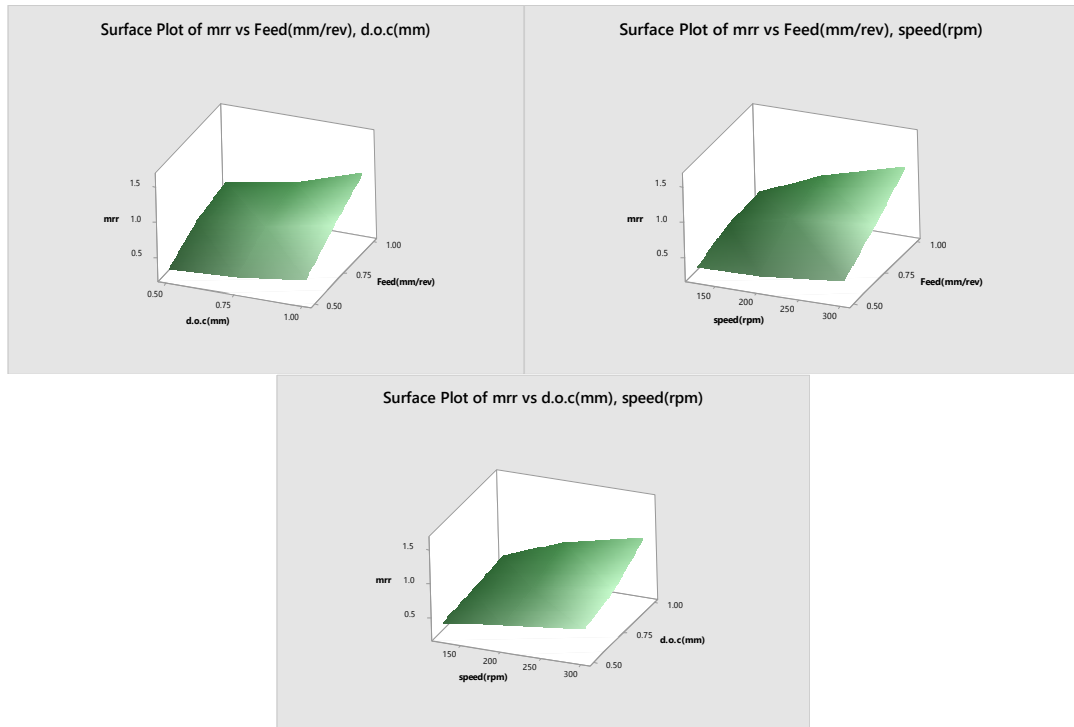
6.7.5 SURFACE PLOT OF MRR

Fig 6.10 : Surface Plots for MRR versus speed ,feed ,depth of cut for HSS
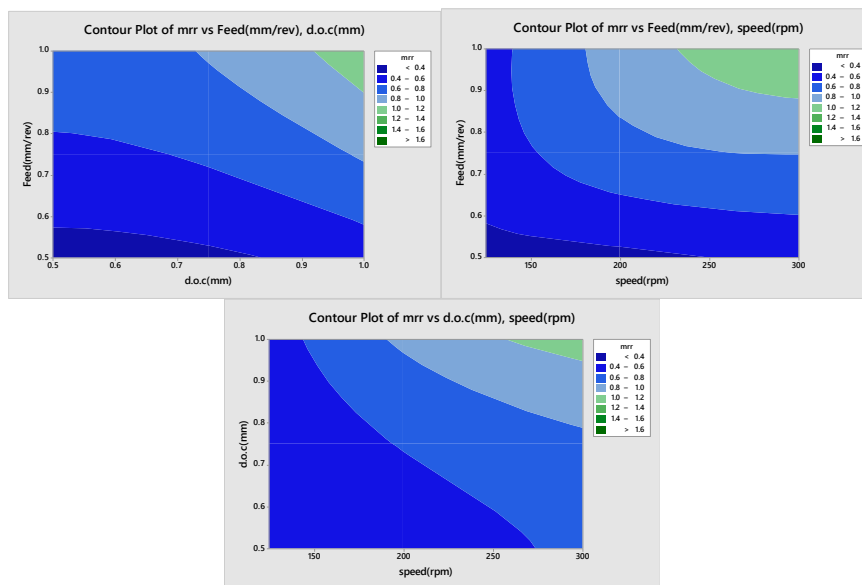
6.7.6 CONTOUR PLOT OF MRR

Fig 6.11 : Contour Plots for MRR versus speed ,feed ,depth of cut for HSS
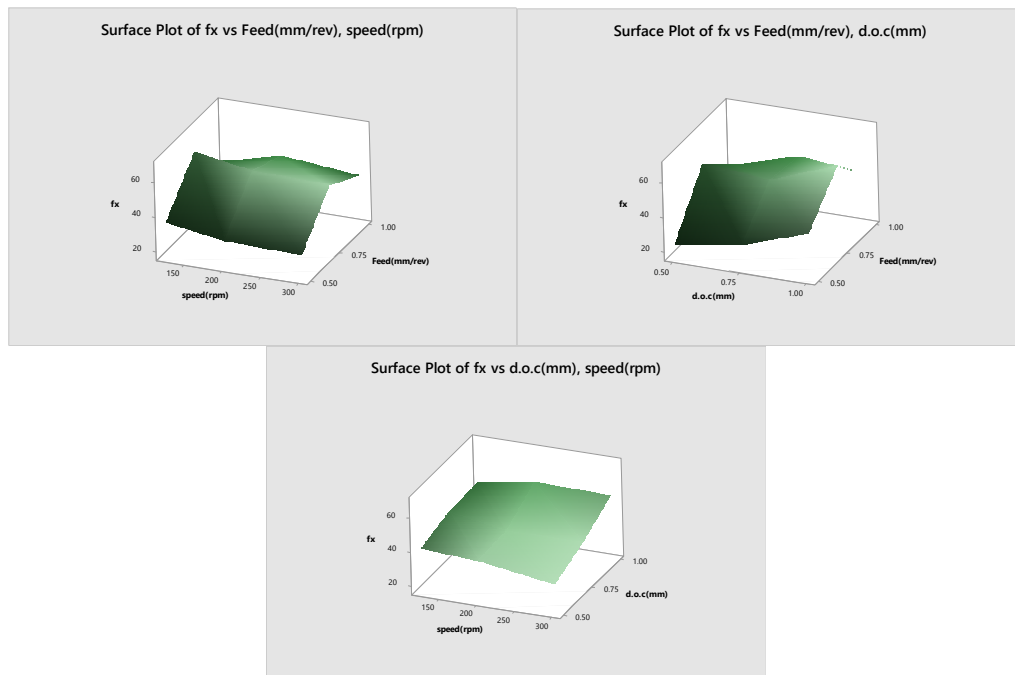
6.7.7 SURFACE PLOT OF F_X

Fig 6.12 : Surface Plots for F_X versus speed ,feed ,depth of cut for HSS

6.7.8 CONTOUR PLOT FOR F_X

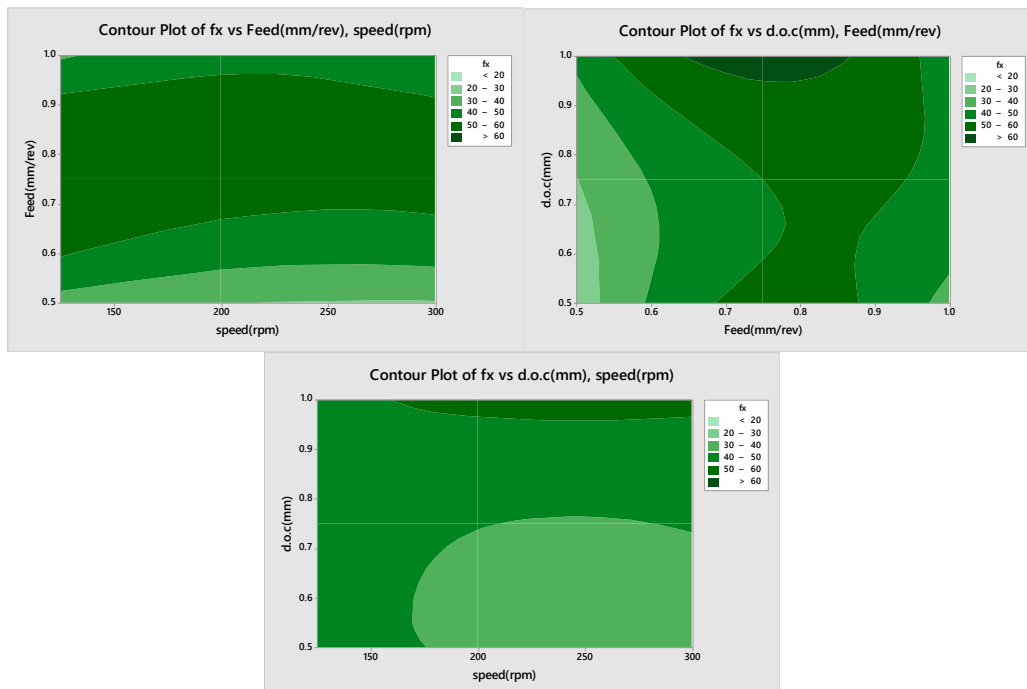Fig 6.13 : Contour Plots for F_X versus speed ,feed ,depth of cut for HSS
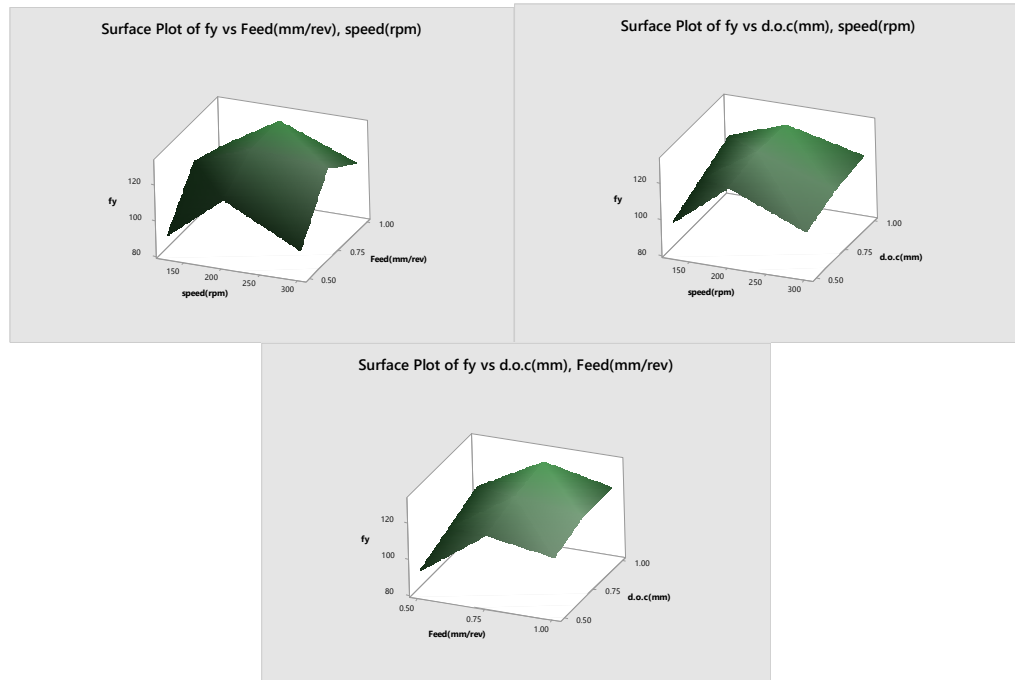
6.7.9 SURFACE PLOT FOR F_Y

Fig 6.14 : Surface Plots for F_Y versus speed ,feed ,depth of cut for HSS
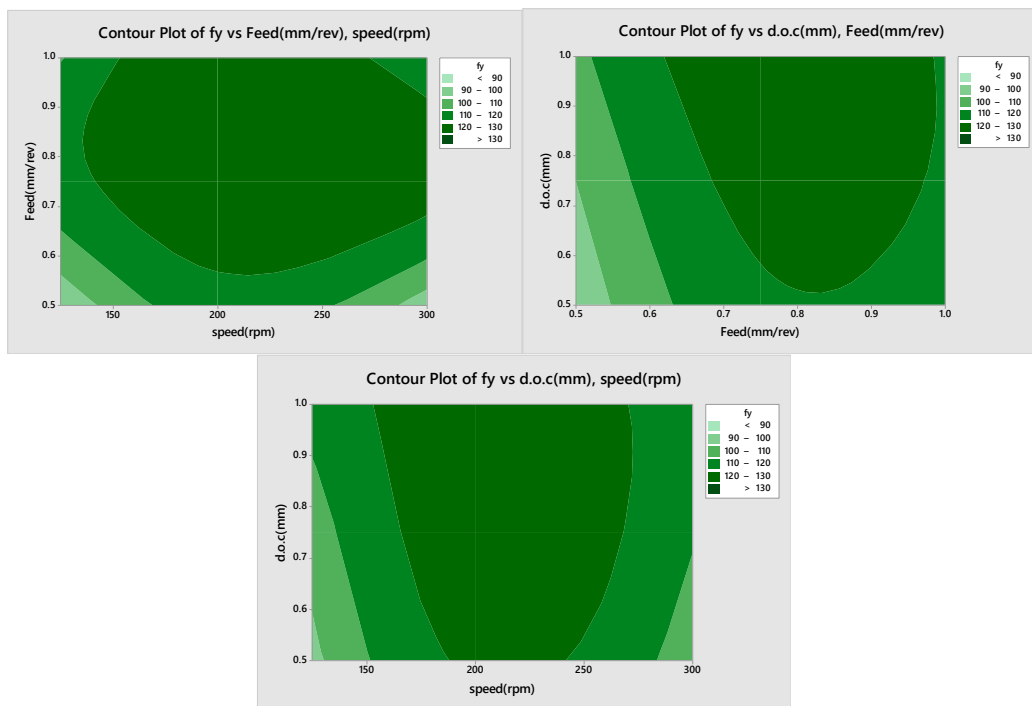
6.7.10 CONTOUR PLOT FOR F_Y

Fig 6.15 : Contour Plots for F_Y versus speed ,feed ,depth of cut for HSS
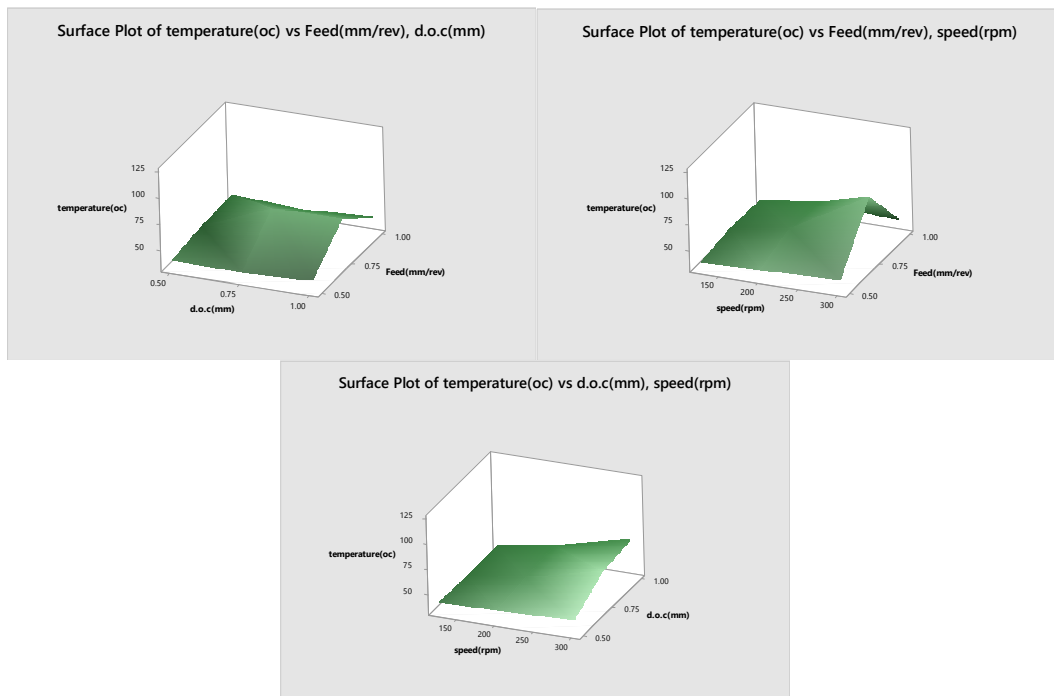
6.7.11 SURFACE PLOT FOR TEMPERATURE

Fig 6.16: Surface Plots for Temperature versus speed ,feed ,depth of cut for HSS
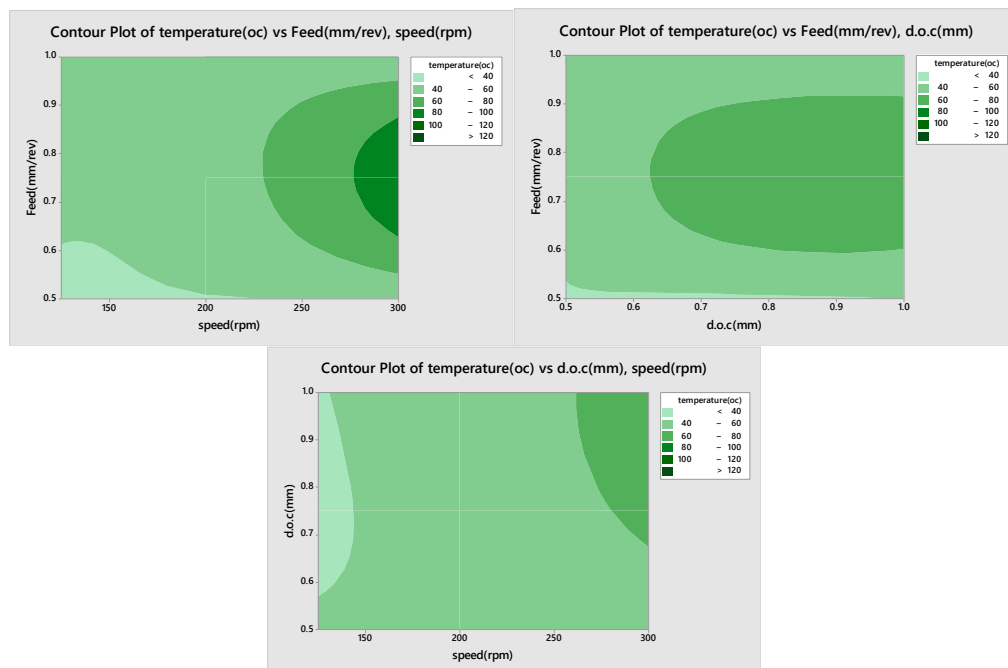
6.7.12 CONTOUR PLOT FOR TEMPERATURE

Fig 6.17: Contour Plots for Temperature versus speed ,feed ,depth of cut for HSS

6.8 MULTI RESPONSE OPTIMISATION

6.8.1 RESPONSE OPTIMISATION

```
Response       Goal      Lower  Target  Upper  Weight
mrr(*10^-4)  Maximum   0.1051   2.103              1
fy           Minimum           64.000    100       1
fx           Minimum           22.000     69       1
temperature  Minimum           34.000     46       1


Multiple Response Prediction


Variable  Setting
speed     300
Feed      1
d.o.c     0.5
```
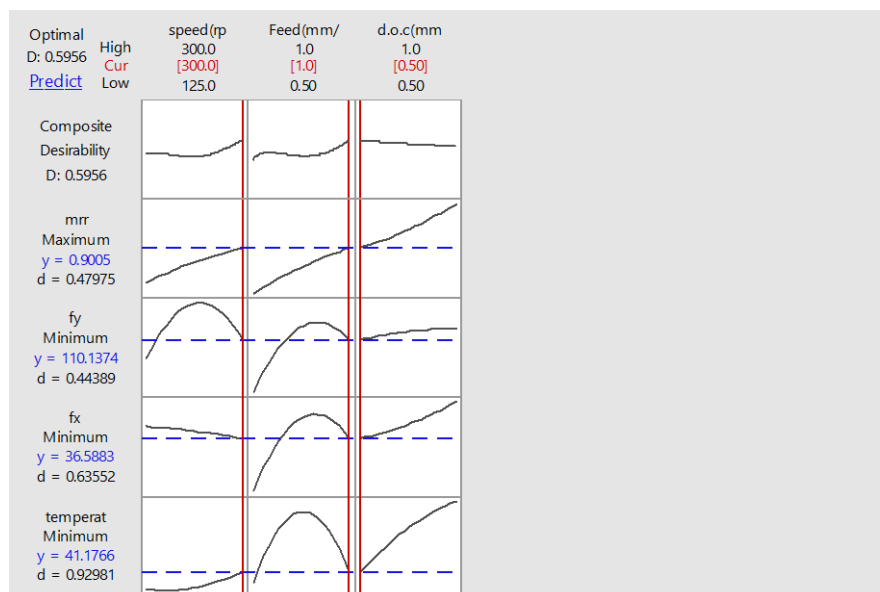
6.8.2 Response

Fig 6.18: Response Optimisation of MRR,F_X,F_Y,Temperature for HSS

6.9 Optimization

Many designed experiments involve determining optimal conditions that will produce the "best" value for the response.

Depending on the design type (factorial, response surface, or mixture), the operating conditions that can control may include one or more of the following design variables: factors, components, process variables, or amount variables.

In product development, there is need to determine the input variable settings that result in a product with desirable properties (responses). Since each property is important in determining the quality of the product, there is need to consider these properties simultaneously. Optimal settings of the design variables for one response may be far from optimal or even physically impossible for another response. Response optimization is a method that allows for compromise among the various responses.

• Response Optimizer − Provides with an optimal solution for the input variable combinations and an optimization plot. The optimization plot is interactive; we can adjust input variable settings on the plot to search for more desirable solutions.

• Overlaid Contour Plot − Shows how each response considered relates to two continuous design variables (factorial and response surface designs) or three continuous design variables (mixture designs), while holding the other variables in the model at specified levels. The contour plot allows visualizing an area of compromise among the various responses.

6.9.1 Response Optimizer

Stat > DOE > Response Surface > Response Optimizer

- Use response optimization to help identify the combination of input variable settings that jointly optimize a single response or a set of responses. Joint optimization must satisfy the requirements for all the responses in the set, which is measured by the composite desirability.

- Minitab calculates an optimal solution and draws a plot. The optimal solution serves as the starting point for the plot.

- This optimization plot allows to interactively changing the input variable settings to perform sensitivity analyses and possibly improve the initial solution.

- The optimization plot as shown signifies the affect of each factor (columns) on the responses or composite desirability (rows). The vertical red lines on the graph represent the current factor settings.

- The numbers displayed at the top of a column show the current factor level settings (in red).

- The horizontal blue lines and numbers represent the responses for the current factor level. Minitab calculates maximum material removal rate.

CHAPTER 7

CONCLUSIONS

- From the optimisation plot it is clear that while machining an EN9 material a HCS tool is to be used .

- Mini Tab produces a direct equation with the combination of controlled parameters which can be used in industries to know the Values of material removal rate, cutting forces both on x and y directions and cutting temperature.

- Hence the optimal solution for material removal rate is $1.3403*10^{-4}$ (m^3/s) , cutting force on the x-direction is 27.5956N, cutting force is y-direction is 70.7985N and temperature 34.2315°c will be obtained when the EN9 workpiece is machined at speed 300rpm, feed 1(mm/rev) and depth of cut 0.5(mm) using HCS as a tool for turning.

- Hence the optimal solution for material removal rate is $0.9005*10^{-4}$(m^3/s) , cutting force on the x-direction is 36.5993N, cutting force is y-direction is 110.137N and temperature 41.766°c will be obtained when the EN9 workpiece is machined at speed 300rpm, feed 1(mm/rev) and depth of cut 0.5(mm) using HSS as a tool for turning.

BIBLIOGRAPHY/REFERENCES

[1] S. Thamizhmanii, S. Saparudin, S. Hasan, 2007, "Analyses of Surface Roughness by turning process using Taguchi method". Journal of Achievements in Materials and Manufacturing Engineering, Volume 20 Issues 1-2 January-February 2007, pp.503-506.

[2] Leonardo R. Silva, A. M. Abrao, J. Campos Rubio, J. Paulo Davim, 2008, "A Note on the Influence of Cutting Speed on Cutting Forces and Surface Finish During Precision Turning Of AISI 1045 Steel". Annals of the Faculty Of Engineering Hunedoara – Journal of Engineering. Tome VI (year 2008). Fascicule 2 (ISSN 1584 – 2665), pp.113-118.

[3] Raviraj Shetty, R. Pai, V. Kamath and S. S. Rao, 2008, "Study On Surface Roughness Minimization In Turning Of Dracs Using Surface Roughness Methodology and Taguchi under Pressured Steam Jet Approach". ARPN Journal of Engineering and Applied Sciences (ISSN: 1819-6608) VOL. 3, NO. 1, February 2008, pp.59-67.

[4] Raviraj Shetty, R. Pai1, S.S.Rao, 2009, "Experimental Studies on Turning of Discontinuously Reinforced Aluminium Composites under Dry, Oil Water Emulsion and Steam Lubricated Conditions Using TAGUCHI's Technique". G.U. Journal of Science 22(1), pp. 21-32.

[5] Karin Kandananond, 2009, "Characterization of FDB Sleeve Surface Roughness Using the Taguchi Approach". European Journal of Scientific Research ISSN 1450-216X Vol.33 No.2 (2009), pp.330-337.

[6] Sehgal A.K, Agarwal Anuj and Agarwal Amit, 2009, "Surface Roughness Optimization in an End Milling Operation based on Taguchi Design of Experiment: A Comparative Analysis". International Conference on Advances in Industrial Engineering Applications, pp.1-6.

[7] T. Rajasekaran, K. Palanikumar, B. K. Vinayagam, 2010, "Application Of Taguchi Method In The Selection Of Cutting Parameters When Turning PA6 Using CBN Cutting Tool". International Conference on Advances in Industrial Engineering Applications, pp.1-7.