A THESIS REPORT

ON

ANALYSIS OF SURFACE ROUGHNESS IN DRILLING USING RESPONSE SURFACE METHODOLOGY

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

MASTER OF TECHNOLOGY

IN

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DECLARATION

I hereby declare that the work presented in this report, titled **"ANALYSIS OF SURFACE ROUGHNESS IN DRILLING USING RESPONSE SURFACE METHODOLOGY"**, in partial fulfillment for the award of the degree of M.Tech in Production and Industrial Engineering, submitted in the Department of Mechanical engineering, Delhi Technological University, Delhi, is original and to the best of my knowledge and belief, it has not been submitted in part or full for the award of any other degree or diploma of any other university or institute, except where due acknowledgement has been made in the text.

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CERTIFICATE

This is to certify that the research work embodied in this dissertation entitled **"ANALYSIS OF SURFACE ROUGHNESS IN DRILLING USING RESPONSE SURFACE METHODOLOGY"** submitted by Bhupendra Singh, Roll no. 2K13/PIE/07 student of Master of Technology in Production and Industrial Engineering under Department of Mechanical Engineering, Delhi Technological University, Delhi is a bonafide record of the candidate's own work carried out by him under our guidance. This work is original and has not been submitted in part or full for award of any other degree or diploma to any university or institute.

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ABSTRACT

Drilling is one of the elementary machining processes of making holes and it is used in manufacturing industry like watch manufacturing industry, Aerospace industry, Automobile industry, medical industries and semiconductors.

In this study, an attempt has been made to minimize the surface roughness and torque in the drilling process on an EN-31 specimens of height (70mm), diameter (40mm) by application of the DOE (Design of Experiment) method integrated with RSM. Taking into account the drilling speed, feed rate and the drill diameter the machining controlled parameter thrust, torque and surface roughness, are optimized based on the RSM method. A Run order was developed by taking the three factors each having 3 levels using Statistical package. Based on the sequence, drilling was done by taking HSS drill bit of different size diameter. The resultant data are analyzed by RSM to find out a combination of optimal drilling conditions. In particular, it is found that high speed and low feed and small diameter is giving a better result having low surface roughness, torque and thrust.

Keywords : response surface methodology, central composite design, minitab, drilling, speed , drill diameter, feed, surface roughness, thrust,torque.

LIST OF ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
d	Drill diameter(mm)
s	Speed or revolution per minute
f	Feed rate (mm/min)
RSM	Response surface methodology
CCD	Central composite design
$\alpha, \varepsilon, \gamma$, β, δ, μ	Constants

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Chapter 1 INTRODUCTION

Drilling is a method to cut holes through a specimen in which various improvements and studies have been carried out over a span of time. Drilling is essentially for manufacturing industry like watch manufacturing industry, Aerospace industry, Automobile industry, semiconductors and medical industries. Drilling is required in industries for assembly related to mechanical fasteners. It was stated that approximately 55000 holes were drilled as a complete single unit in the production of Air bus A350 airplane.

The manufacturing industries knowingly have focused their attention on the accuracy in the measurements and surface roughness. This is most important factor and it depicts the quality of the product which is in the consideration. Surface roughness is always tried to be as minimum as possible as then it enhances traits of the material. In the process of obtaining the optimized or most feasible parameters there has been a shift in the ideology now the most preferred characteristic is surface finish.

The requirement to find and chose and induct the optimal conditions is now on the high importance. In the process of developing a surface of the output it is of utmost importance to study and analyze the present scenario of the drilling process. Conventional methods paves the way for high surface roughness and also causes a decrement in the functionality and the usage of the object due to non-optimization of the resources which causes the resources to be wasted and bring no good to the firm. This state also leads to the high investment in the process of drilling or machining and also causes to have high surface roughness. Surface roughness is actually an outcome of the parameters which control the shape and size of the drilling tool. Surface roughness is the factor which is not only hard to measure but also it is very versatile and it depends upon every minute input parameter. So it becomes highly compulsive to have a detailed study of the process to keep the roughness in limits. The parameters on which it depends may be controllable or not.

Controllable parameters:-

1. Cutting speed
2. Tool geometry
3. Feed
4. Tool setup

Non controllable parameters:-

1. Tool wear
2. Machine vibration
3. Degradation of work piece
4. Tool material

These parameters are not put in the desired range easily. The cutting parameters which are included in this project work are:-

1. Depth of cut
2. Feed
3. Cutting velocity.

1.1. WHY THIS WORK AND ITS IMPORTANCE

Surface roughness has been one of the most important parameters in the process of drilling as the use of inside surface depends a lot on the finish produced by the drilling process. Surface roughness creates an index of quality which can be used to control the use of the work piece effectively and in a very better way. So, it becomes of high importance to control and understand the nuances of the surface roughness so as to use it in different ways in the industry and home.

Also the works that has been previously done on the subject were done manually there was less work done by the better design of experiment technique RSM. this enabled me to take up the work and pursue it in the bigger aspect. the material also is not an old material but a relatively new and is having better and good properties than the previously available material.

1.2. MOTIVATION

Drilling has been a widely studied topic in the field of engineering and production due to its wide acceptability and its application. Various works have been done on the topic but due to technological advancements in the industry the studies have proved to be outdated which made the drilling process a new topic for the research. Due to advancement of the technological aspects and techniques all previous works have been proved to be futile in case of new materials in the market.

Due to this gap found in the study of drilling the drilling was taken up as the project to study the various responses on a new material and comparatively new optimization techniques.

1.3. RESPONSE SURFACE METHODOLOGY

RSM is nothing but an amalgamation of the statistical methods available and their usage in the mathematical manner so that they could be utilized to find out the desired values which are to be controlled. It is a method which uses apt number of experiments to find out the solutions to the multi variable problems which depend upon the factors.

Graphical depictions of these obtained problems are coined as the response surfaces, which are used to designate the individual and combined effect of the input variables on the output and to find out the relationship these variables share among themselves or between the output also known as response.

Uses of RSM:-

1. To find out the factor level and this will be able to satisfy the desired dimensions.
2. To find the relationship of responses on individual input parameter.
3. To obtain a quantitative knowledge of the system performance in the area
4. To forecast the properties of the product and to find out the responses it would give when the obtained settings are given.
5. To find out the all the necessary situations for the stability of the process.

Hence, RSM is a better tool for optimization and able to forecast effectively the effect of parameters on response.

1.4. TORQUE AND THRUST

Drilling is the most important conventional machining process affiliated to the chipboard processing. In any industry or firm there is high requirement of holes to be produced in the object so as to hold the object or specimen to measure the forces and torque in the body. Very important part which affects this force is the geometry of tool and controls the outcomes.

Chip drilling is a drilling process which asks for a very unique set of factors to be set so as to bring the feasible areas in consideration. In this drilling process the parameters or the variables are given importance as they can control the outcome effectively.

Any good drilling model is aimed to have precise feed rates, speeds of spindles, and geometries. The analysis of drilling process is known to have complex geometries in it. The complex and intricate geometries of the tool are reason for the varying torque and thrust in the process.

Drill bits are the parts which are used to cut the material and they have a wide variety in their compositions but the shape of such bit tools is mostly cylindrical as the hole to be produced is the basic aim and this can be produced by cylindrical tool only. These bits are made in combination to the static part of the machine which causes the bit to be rotated and produce the desired effect. The bits have two edges.

Exceptionally, specially-shaped bits can cut holes of non-circular cross-section.

Variety of materials is taken in consideration to make the drill bits, which rely upon the shape the feed the speed at which the hole is to be produced.

1.3.1. Steels: Bits made out of the high carbon steels are much better than the low carbon steels they have better properties and ability to drill the other materials with ease.

a) High speed steel (HSS) is a tool steel, it is hard and much effective against high temperature and better than steel of high carbon.

b) Cobalt steel alloys are nothing but alloys formed of HSS and cobalt as its main components they are able to sustain their properties at a high temperature and can drill stainless steels.

1.3.2. Others

a) Tungsten carbide and other carbides are substances which are extremely hard to and can drill any material. These materials are used to produce holes where the holes are to be produced in hard materials and the life of the tools is also has to be high.

b) Polycrystalline diamond (PCD): it is the hardest of all materials that are known to the people. It consist of a layer of particles of diamond which provide the body with strength for high cutting power due to diamond whereas, the tungsten provides the resistance to abrasion. It is known that PCD is never operated upon the ferrous materials due to the chemical reaction that takes place in the carbon and iron and formation of an interstitial compound.

1.3.3. Coatings

a) Titanium nitride (TiN) is a highly hard material which is ceramic in nature and used to coat the HSS bit.

b) Titanium aluminum nitride (TiAlN) is another type of layer which enhances properties.

c) Titanium carbon nitride (TiCN).

d) Diamond powder is an abrasive material and used for cutting hard materials.in this process a huge quantity of heat is generated due to friction and water is provided along with it to stop the damage to the work piece.

e) Zirconium nitride is another drill bit with high hardness and strength.

1.5. SURFACE ROUGHNESS

Surface roughness is coined as the deviation or the bifurcation of the surface vector from its real value. If the deviation is more then the surface is rough and if they are small then the surface is smooth. Roughness is the component of surface texture and it consist of the waviness and lay.

Waviness : it is the regular up and down movement of the surface which causes the deviation from the original required pattern.

Lay : it is the marks of the tool made in the cutting process which cause the surface to be rough. These are of various types:

1. Circular
2. Multidirectional
3. Perpendicular
4. Concentric
5. Radial
6. Parallel

There are various methods to measure surface roughness in the material.

1. Ra value method : average of all roughness without sign.
2. RMS value method : root mean square average of all deviations.
3. Center line average method : average of the peaks and valleys about a center line with sign.

Chapter 2 LITERATURE REVIEW

In this we studied certain research papers collected by us and making these papers as our source of light, we proceeded in the direction of measurement of torque and thrust.

Papers that were studied:-

C. Tsao and H. Hoeing, presented the prediction and evaluation of thrust force and surface roughness in drilling of composite material using candle stick drill. The approach was based on Taguchi method and the artificial neural network. The experimental results indicated that the feed rate and the drill diameter were the most significant factors affecting the thrust force, while the feed rate and spindle speed contributed most to the surface roughness. In this study, the objective was to establish a correlation between the feed rate, spindle speed and drill diameter with the induced thrust force and surface roughness in drilling composite laminate. correlations were obtained by multi-variable regression analysis and radial basis function network (RBFN) and compared with the experimental results. The results indicated that the RBFN is more effective than multi-variable regression analysis. It used Kistler 9257 piezoelectric dynamometer to measure the forces.

D.A. Stephson et. al. developed a model for calculating main cutting edge torque, thrust, and radial force distributions for drilling gray cast iron with solid carbide and carbide-tipped drills. Unlike previous models, this model was applicable to arbitrary point geometries and includes radial forces due to point asymmetry. A general parametric method for characterizing complex point geometries was first explained. Using this method, along with empirical cutting force models from end turning tests, torque, thrust, and radial force calculations are carried out for ten representative drills covering a range of available geometries. Calculated and measured torque values agreed to within the repeatability of the measurements. Calculated thrust force values were reasonable, but were significantly lower than measured values in most cases, since chisel edge contributions are not included.

Diana M. Rincon and A. Galip Ulsoy found that Drill bit vibrations can have an adverse effect on drilling performance resulting in lobed holes, burr formation and tool breakage. An analytical model for predicting torque, thrust and radial forces in drilling was developed. The model included the effects of the drill bit transverse deflections which lead to variations from the mean values in the cutting forces. Simulations for a drill, exhibiting increasing elliptical translational motion due to drill vibrations, indicate a significant increase in the ranges of the torque and thrust while maintaining essentially constant mean values. The same qualitative trends are also observed experimentally. The model, when drill vibrations are negligible, reduces to previous models for predicting the mean torque and thrust in drilling. The mean drilling torque and thrust values predicted are in good agreement with experimental data and with previously published models.

L.B. Zhang et. al. showed that delamination is a dramatic problem associated with drilling fiber-reinforced composite materials (FRCMs), which, in addition to reducing the structural integrity of the material, also resulted in poor assembly tolerance and has the potential for long-term performance deterioration. Solution to the problem lied in reducing the thrust force of drilling. In this paper, a theoretical analysis for predicting mean values of thrust and torque in vibration drilling FRCMs was presented. This was based on mechanics of vibration of cutting analysis and the continuous distributions of thrust and torque along the lip and the chisel edge of a twist drill. The result of the simulation study had shown a very good agreement between the theoretical predictions and the experimental evidence. On the same cutting conditions, the thrust and the torque by the vibration drilling method were reduced by 20–30 percent, compared with conventional drilling.

L.P. Wang et.al. developed a method for predicting the thrust and torque in vibration micro drilling. The model was based on the mechanics of vibration cutting analysis, which involved the development of a dynamic uncut chip thickness and its analysis for each vibration cutting element at the lips and chisel edge. The proposed method had been tested for a range of vibration parameters and feeds. The predicted thrust and torque values had been equated with those obtained in vibration micro-drilling experiments.

These comparisons showed good agreement between the theoretical predictions and the experimental evidence.

L.P. Wang et. al. found the predictive model for dynamic thrust and torque in vibration drilling. The model was based on the mechanics of vibration cutting analysis, assuming that the deformation process at the lips and chisel edge is treated as a number of vibrations cutting elements, each with different dynamic characteristics. The result of a simulation study conducted for a low frequency range had shown a very good agreement between the theoretical predictions and the experimental evidence. The simulation result indicates that the thrust and torque possess a pulse cutting property and were significantly affected by vibration parameters.

According to Liu Dong et al, The Composites are difficult machining materials which widely used in aerospace industry due to their excellent mechanical properties. Tool wear and delamination are considered the major concern in manufacture the parts and assembly. The thrust force and torque affect the tool life and delamination mostly. This paper investigated the drilling force and torque of carbon fibred composite with carbide drilling tools brazed diamond. The experiments were carried out under air cooling cutting conditions and the regulation of the drilling force influenced by the feed rate and cutting speed was obtained. The exponential formula of drilling force and torque were obtained through regression analysis method and results show that the model of drilling force fitted the experimental data well and the relations of drilling force and drilling parameters approximately satisfies exponential function.

M. Elhachimi et.al. set a new theoretical model to predict thrust and torque in high speed drilling was presented. The method consisted of determining the continuous distributions of thrust and torque along the lip and the chisel edge of a twist drill. This calculation used the oblique cutting model for the lip and the orthogonal cutting model for the chisel edge. Thrust and torque were obtained in terms of the geometric features of the drill, the cutting conditions and the properties of the machined material were studied. This analytic model also showed the determination of the influence of the drill geometry on thrust and torque in drilling.

Ranganath M S. et. al. paper was a review paper of various papers published on the rsm technique to find out the best optimization technique for the analysis of various cutting parameters. Like cutting speed, feed, depth of cut on the surface roughness. It assumed that Surface roughness has become the most significant technical requirement and it is an index of product quality. In order to develop a surface roughness model and optimize, it was essential to understand the current status and optimization through that variable which is surface roughness.

Ranganath M S. et. al. conducted a series of experiments on an aluminum material to find out the optimization process on them. these experiments were basically classified in taguchi or the RSM process so as to decide which is better. The process is done by the design of experiments and the RSM technique was found to better and predicted better results and good surface finish.

S. Madhavan et. al. reported the effects of thrust force during the drilling of 10mm diameter holes in 20mm thick Carbon Fibre Reinforced Plastic composite laminate using HSS, Solid Carbide (K20) and Poly Crystalline Diamond insert drills. Experiments were conducted on a vertical machining centre using Taguchi design of experiments. A model was developed to correlate the drilling parameters with thrust force using RSM. The results indicated that the developed model was suitable for the prediction of thrust forces in drilling of CFRP composites. The influence of different parameters on thrust force of CFRP composites had been analyzed through contour graphs and 3D plots. The investigation had revealed that the type of drill geometry affects the thrust force significantly followed by the feed rate and the speed. This reveals that drill geometry had significant effect on the thrust force. The thrust force generally increases as the speed increases but it further decreases in the case of Carbide and PCD tool.

Vaishak N L, et.al. This research process was an effort to understand the influence of important machining parameters like thrust force and torque that were produced during drilling of Granite particulate Reinforced Epoxy Composite. Experiments were conducted by using High Speed Steel (HSS) Drill Bits of different diameters. The results also depicted the cutting speed and feed speed act as an important variable that influences drilling induced damages.

It was observed that:

1. Amongst the two drill bits used, 4mm drill bit recorded higher values for thrust force and Torque.
2. It is observed that drilling induced damage (Delamination Factor) is heavily dependent on both feed speed, as well as cutting speed.
3. Drilling induced damage decreases with increase in cutting speed and increases with increase in feed speed.
4. Drilling damage induced by a 4mm drill was comparatively higher than that induced by a 6mm drill relatively due to high amount of thrust and torque forces.

This torque and thrust can be calculated by various procedures as it depends upon various independent variables which came into play during the drilling process and these vary from the depth of cut to feed to speed or even the surface roughness to be produced or initial roughness. C.Tsao et. al. [1] reported that the feed rate and the drill diameter are recognized as the most significant factors affecting the thrust force. Depending upon these variables various researchers used various methods to find out the force and thrust produced in the drilling process.

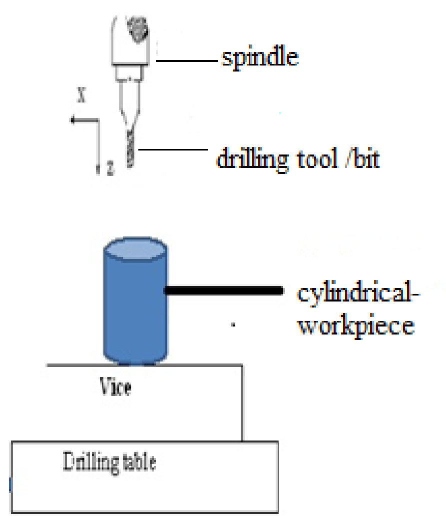

Figure 1 : a schematic diagram of drilling process

Different methods adopted to find force and thrust in the drilling process are

Investigators have studied analytically and experimentally that delamination in drilling is correlated to the thrust force during exit of the drill. Experiments indicate that there exists a critical thrust force below which no delamination occurs (1).

A predictive model for the dynamic thrust and torque in vibration drilling. The model is based on mechanics of vibration cutting analysis, assuming that the deformation process at the lips and chisel edges is treated as a number of vibration cutting elements, each with different dynamic characteristics.(4)

By conducting experiments in various atmosphere conditions and use of different type of design of experiments to get the result.(5)

The method of calculation used the orthogonal cutting model and the oblique cutting model, and was also used in 1979 by Wiriyacosol and Armarego [4]. Basically, this method consists of dividing the cutting edges into a limited number of cutting elements. These elements were assumed to be oblique cutting edges on the cutting lip and orthogonal cutting edges on the chisel edge. This calculation used empirical equations established from orthogonal cutting tests.

RESPONSE SURFACE DESIGN

A set of advanced design of experiments (DOE) techniques that help you better understand and optimize your response. Response surface design methodology is often used to refine models after important factors have been determined using factorial designs; especially if you suspect curvature in the response surface.

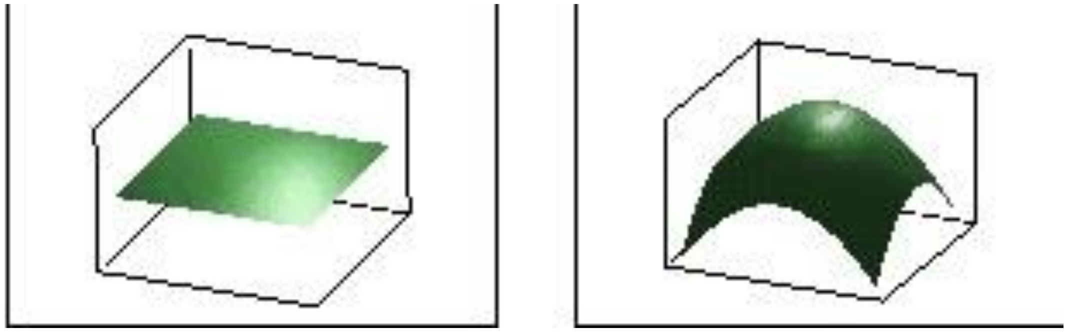

Figure 2 : surface representation in RSM and other technique

The difference between a response surface equation and the equation for a factorial design is the addition of the squared (or quadratic) terms that allow you to model curvature in the response, making them useful for:

1. Understanding or mapping a region of a response surface. Response surface equations model how changes in input variables influence a response of interest.
2. finding the levels of input variables that optimize a response.
3. selecting the operating conditions to meet specifications.

For example, you would like to determine the best conditions for injection-molding a plastic part. You first used a factorial experiment to determine the significant factors (temperature, pressure, cooling rate). You can use a response surface designed experiment to find the optimal settings for each factor.

There are two main types of response surface designs:

a. **Central Composite designs** can fit a full quadratic model. They are often used when the design plan calls for sequential experimentation because these designs can incorporate information from a properly planned factorial experiment.
b. **Box-Behnken designs** typically have fewer design points, thus, they are less expensive to run than central composite designs with the same number of factors. They allow efficient estimation of the first- and second-order coefficients; however, they can't incorporate runs from a factorial experiment

METHODOLOGY OF RSM:-

Whole process of rsm can be divided into different parts and those parts are the sequences in which the process has to be done.

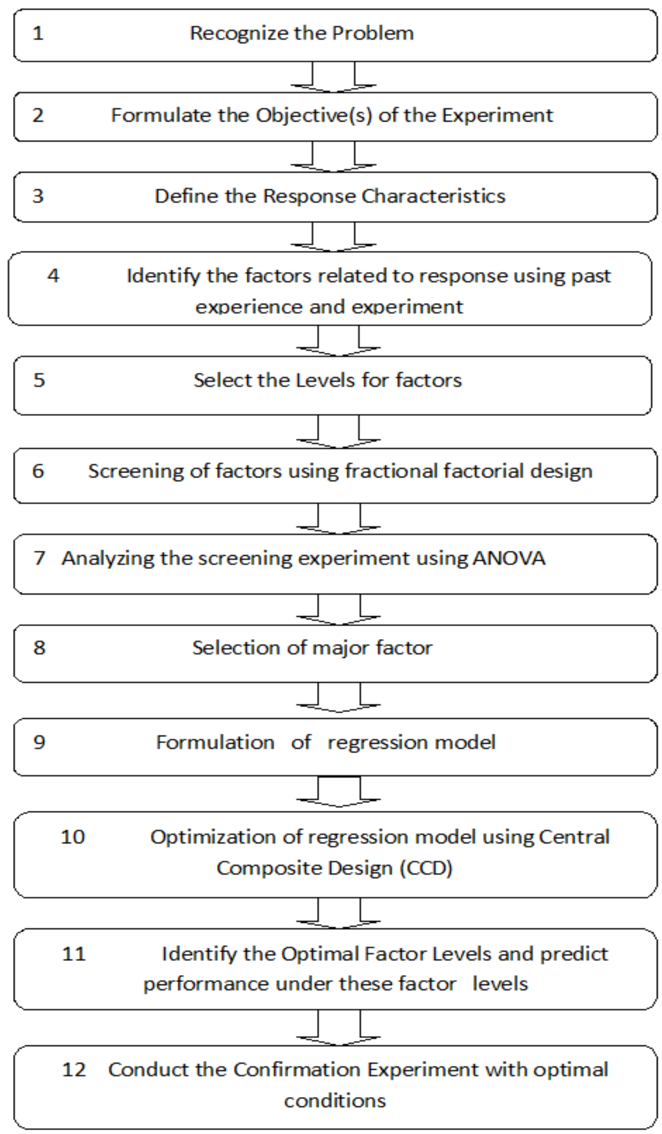

Figure 3: steps in RSM (12)

In design optimization using RSM, the first task is to determine the optimization model, such as the identification of the interested system measures and the selection of the factors that influence the system measures significantly. To do this, an understanding of the physical meaning of the problem and some experience are both useful. After this, the important issues are the design of experiments and how to improve the fitting accuracy of the response surface models. DOE techniques are employed before, during, and after the regression analysis to evaluate the accuracy of the model. RSM also quantifies relationships among one or more measured responses and the vital input factors.

RSM, is a collection of mathematical and statistical techniques in which a response of interest is influenced by several variables and the objective is to optimize this response. For example, suppose that a chemical engineer wishes to find the levels of temperature (x1) and pressure (x2) that maximize the yield (y) of a process. The process yield is a function of the levels of temperature and pressure, y = f (x1, x2) +e

Where e represents the noise or error observed in the response y. Then the surface depicted by h= f (x1, x2), which is called a Response surface. We usually represent the response surface graphically, where h is plotted versus the levels of x1 and x2. To help visualize the shape of a response surface, we often plot the contours of the response surface as well. In the contour plot, lines of constant response are drawn in the x1, x2 planes. Each contour corresponds to a particular height of the response surface. Objective is to optimize the response. In RSM, polynomial equations, which explain the relations between input variables and response variables, are constructed from experiments or simulations and the equations are used to find optimal conditions of input variables in order to improve response variables. For the design of RSM, many researchers have used central composite design (CCD) for their experiments. CCD is widely used for fitting a second-order response surface. CCD consists of cube point runs, plus center point runs, and plus axial point runs.

The three factors speed, feed rate, depth of cut, selected in the screening experiment, will be used in CCD. The process can be studied with a standard RSM design called a Central composite design (CCD). The factorial portion is a full factorial design with all factors at three levels, the star points are at the face of the cube portion on the design which correspond to value of -1. This is commonly referred to as a face centered CCD. The center points, as implied by the name, are points with all levels set to coded level 0, the midpoint of each factor range, and this is repeated six times. Twenty experiments to be performed. For each experimental trial, a new cutting edge to be used. The latest version of the Minitab or Design Expert may be used to develop the experimental plan for RSM. The same software can also be used to analyze the data collected.

Objective

Our goal is to start from using our best prior or current base and find for the optimum spot where the response is either maximized or minimized.

Here are the models that we will use.

Screening Response Model :

$$y = \alpha + \beta x_1 + \gamma x_2 + \delta x_1 x_2 + \varepsilon \qquad (1)$$

The screening model that we used for the first order situation involves linear effects and a single cross product factor, which represents the linear x linear interaction component.

Steepest Ascent Model

If we ignore cross products which gives an indication of the curvature of the response surface that we are fitting and just look at the first order model this is called the steepest ascent model:

$$y = \alpha + \beta x_1 + \gamma x_2 + \varepsilon \qquad (2)$$

Optimization Model :

After this, it is known that we are somewhere near the maximized or optimized value so, a second order model. This includes in addition the two second-order quadratic terms.

$$y = \alpha + \beta x_1 + \gamma x_2 + \delta x_1 x_2 + \theta x_1^2 x_2^2 + \varepsilon \qquad (3)$$

If the plot is in more than 2 dimensions, the method is not best suited as per the obtained plot. The method of steepest ascent tells where to take new measurements, and the response at those points can be recorded. it might move a few steps and it may be seen that the response persistently strived to move up or perhaps not - then you might do another first order experiment and reorganize the efforts. The point is, when the experiments are done for the second order model, it is hoped that the optimum will be in the range of the experiment - if it is not, then, it is extrapolation to find the optimum. In this case, the safest thing to do is to do another experiment around this estimated optimum. Since the experiment for the second order model requires more runs than experiments for the first order model, it is required to move into the right region before starting fitting second order models.

Steepest Ascent - The Second Order Model

This second order model includes linear terms, cross product terms and a second order term for each of the x's. If in generalized way, various values have k first order terms, k second order terms and all possible pairwise first-order interactions. The linear terms just have one subscript. The quadratic terms have two subscripts. There are k*(k-1)/2 interaction terms. To fit this model, it is needed to have a response surface design that has more runs than the first order designs used to move close to the optimum.

This second order model is the basis for response surface designs under the approximation that optimized value is not a perfect quadratic polynomial in k dimensions, but it provides a good approximation to the surface near the maximum or a minimum.

Chapter 3 EXPERIMENT SET-UP

3.1. MACHINE

Machines used in drilling are of numerous types depending upon the speed of cut, size, depth of cut an also the work-pieces on which machining operation is to be performed.

Radial Drilling Machine:

It is a machine used for drilling in a specimen of the required or desired hole. These machines are normally used drilling machines which consist of the arm which is radial or can be rotated according to the desired work piece also this machine has its own feed speed and depth of cut which can be set to the automatic. These machines are of three types namely:

1. Plain
2. Semi universal
3. Universal

Drilling machine used in this process is radial and the specifications are as follows;

Table 1 : Machine specifications (Drilling machine)

Radial drilling machine	Type –RM-62
Drilling capacity	50 mm in steel
Drilling rough bores	90 mm in steel
Boring with supported boring bar	1200 mm in steel
Trepanning	200 mm in steel
Tapping whitworth	$1_{3/4}$ inches
Tapic metric fine threads	56 mm
12 spindle speeds	40-1700 rpm
6 spindle feeds	0.12 mm/rev to 1.2 mm/rev

Spindle diameter	81.8
Drilling pressure	1650 kg
Drill power	4.8/6 h.p
Arm elevating motor power	2 H.P
CAPACITIES	
Max drilling radius	1500
Min. drilling radius	530
Max drill transverse	970
Diameter of column sleeve	350
Max distance column to spindle	1325
Min distance column to spindle	355
Max distance base plate to spindle	1450
Min distance base plate to spindle	385
Working surface of base plate length	1490
Width	910
DIMENSIONS	
Base plate overall length	2190
Overall width	925
Swing of arm	1860
Overall height of machine	2760
Approx. net weight	3160
Case dimensions	
Length	2810
Width	1280
Height	2983

Figure 4: drilling machine used in process at metal cutting lab, dtu

The experimental set up was made by connecting the machine and the dynamometer and the results were thus obtained while conducting the experiments.

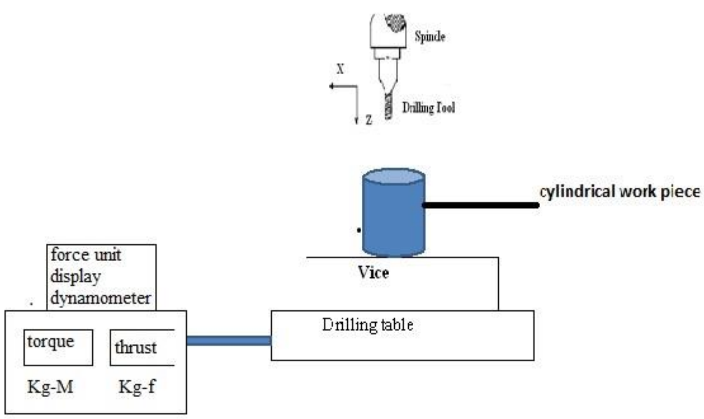

Figure 5 : experimental setup consisting of drilling machine combined with a drill tool and dynamometer.

3.2. MATERIAL /WORKPIECE

The material taken in consideration for the study is a relatively new material of EN series. EN-31 is a type of steel which has high quality and high hardness with respect to other type of steels also this is abrasion resistant steel which is superior to the commonly available steels in the market. The compressive strength is also of high degree and better then the available steels bars.

Significance of EN -31

EN with a capital 'N' designates Europäische Norm which converts to European Standard. En with a lowercase 'n' implies Emergency Number and was used as a representation for various steel grades in BS 970 until a uniform system was set up after the world war 2.

Compositions**:-**

Table 2 : compositions of EN-31

Carbon	0.90-1.20%	Manganese	0.30-0.75%
Chromium	1.00-1.60%	Sulphur	0.050%at max
Silicon	0.10-0.35%	Phosphorous	0.050% at max

Forging process

Heat slowly and start forging in 1000-1050°C. Sufficient time at the forging temperature is given to the steel to thoroughly soak through. Re-heating is done as necessary and not forged below 850°C. After forging EN31 steel, cooling slowly preferably in a furnace is done.

Annealing:-

EN31 is mostly supplied in the annealed and machine able condition. Re-annealing will only be required if the steel is again to be forged or hardened. To anneal, the EN31 steel is heated slowly to 800-810°C, soaked well and allowed to cool in the furnace.

Stress relieving:-

When parts are to be machined heavily, stress relieving will be complimentary prior to hardening. Heating is done to EN31 carefully up to 700°C, soaked well and allowed to cool in air.

Hardening:-

Heating at low pace to the hardening temperature around 800-820°C. Maintained until heat is absorbed through. Plenty of time is given to this process of soaking and then quenched in oil.

Tempering:-

According, to the purpose for which the tool is required the tempering is done, generally in the range of 150°C and 300°C. Heat is soaked well at the selected temperature and absorbs for minimum one hour per 25mm of thickness. Cooling is done slowly in air.

Table 3 : tempering properties of EN-31

Temperature °C	150	200	250	300
HARDNESS	63-62	62-61	61-59	57-56

Heat treatment:-

Heat treatment temperatures, including rate of cooling, heating and absorbing time will vary due to the factors like the shape and size of each EN31 component. Other variations in the process during the heat treatment includes the type of furnace, quenching medium and work piece transport facilities.

Application:

Major applications for EN31 steels include gauges, taps, swaging dies, balls, ejector pins and roller bearings. It is good quality steel demanded for wear resisting machine parts and for press tools which do not require a more complex quality.

Example: Roller Bearings and the ball bearings, spinning tools, Rolls for beadings, Dies and punches also.

3.3. DYNAMOMETER

A dynamometer is a device used to find the torque and thrust in the machine either in drilling or any other machining process. Dynamometer is nothing but a simple electrical machine which is used to measure the value of the force and torque exactly in the process. A dynamometer is first balanced with respect to a known force and then the pointer is moved with respect to the new force coming into action at that point or in that process.

It is nothing but a device for the dynamic calculation of the power produced in the engine while in the common available machine it is used for the prediction of torque.

There are various kinds of dynamometers which are available in the market they are referred according to the source of power they work upon:-

1. Break dynamometer.
2. Break current dynamometer
3. Eddy current dynamometer
4. Hydraulic dynamometer.

Break dynamometers are the oldest in business and are mechanical machines most commonly called as the shoe which when gets in contact of hub rubs against it and produces the desired measurement. Power for the hub to move provided by the engine. Hydraulic dynamometers may be defined as the machines which use hydraulic power to muster up the power to run the components. The load given to the engine is changing depending upon the valve which opens and closes with the change in pressure.

Eddy current dynamometers are devices in which the engine is provided or passed through the current and causes the disk to have an effect of lens law and this causes a force on the machine to move and stick to the hub and thereby measure the thrust or torque.

Changing the amount of current in the machine changes the load settings of the machine in which it is placed. If the dynamometer is made in connection to the engine rod then it is coined as engine dynamometer.

If the dynamometer is made in contact to the driving wheels of the vehicle or then is named as chassis dynamometer.

Figure 6 : dynamometer used in the process at metal cutting lab, dtu

3.4. SURFACE ROUGHNESS INSTRUMENT:

Surface roughness is an important parameter required for the measurement of the quality of the product. Surface measurement is nothing but the comparison of the previously fixed value with the new value obtained.

The taylsurf instrument used in this experiment is a Taylor Hobson unit with surtonic3+ as its product name.

Surtronic 3+ is nothing but an amalgamation of technology so as to achieve high meticulousness and exactitude to have an accurate measurement of surface finish in the process no matter where the work is done, laboratory or the inspection room.

With Surtronic 3+, a beginner with no skills can achieve wide range of skills that can be understood within minutes. In this device the cycles in the function are minimum during the process of measurement and the variations are minute and the response can be obtained on the screen available. The process of measurement is easy and the whole machine can be operated or navigated through a wide variety of navigations and selection menus.

Figure 7 : a taylsurf instrument by taylor hobson surtonic 3+ at metrology lab, dtu

The specifications of the handheld taylsurf used in the measurement are as stated in

table 4.

Table 4 : specification of taylsurf , in metrology lab,DTU

Gauge Range	±150µm (0.006in)
Pick up type	Variable reluctance reluctance
Traverse length (Max)	25.4mm (1.0in)
Stylus	112/1502: Diamond tip radius 5µm (200µin)
	112/1503: Diamond tip radius 10µm (400µin)
Cut Off Values	0.25, 0.8, 2.5, 8mm
Parameters	Ra
Traverse length (Min)	0.25mm (0.01in)
Overall Dimensions	130 x 80 x 65mm (5.1 x 3.3 x 2.5in)
Data Processing Module	185 x 140 x 50mm (7.5 x 5.5 x 2in)
Resolution	0.01µm (0.4µin)
Traverse Speed	1mm/sec (0.04in/sec)
Accuracy of Parameters	2% of reading + LSD µm
Power	Battery (Mains)

The instrument is used on vertical, horizontal or inclined surfaces, along with selected mountings as a bench system for laboratory or batch measurement applications. The holder for measuring is placed at the slide so as to measure the vertical values and it can be easily revolved to various angles for measuring various dimensions.

Advantages of surtonic 3+:

1. Easy to handle in the workshop and laboratory.
2. Simple to use and also fast method.
3. Highly accurate and versatile in its working.
4. A wide range of parameters and high cutoff length for any measurement.
5. Easy to connect to software and automate the process.
6. Ability to process data.
7. Provides many languages.
8. Requires battery source.

3.5. PROCEDURE

Considering the basic aim of analysis of drilling the material was chosen in the process. The material thus selected was EN – 31 which is a relatively new material than any other material used as metal for domestic as well as military purposes.

The material was then brought in the desired shape so that the force and the torque could be measured during the drilling process.

The dimensions required were :-

Length - 70mm

Diameter – 40mm

The specimen thus obtained was then drilled and the recorded accordingly on the desired feed speed and the drill diameter. After the drilling process the surface roughness was measured by the tylrsurf surtonic 3+. This gave the measurements of the surface roughness and thereby the roughness was measured.

After, this process results were used in the minitab and thus the graphs and the plots were obtained.

3.6. SOFTWARE

The software used is minitab 15 which is used to draw the graphs and plots for the desired factors and responses. Minitab is a not only a software but a complete package of statistical tools designed and produced at the Pennsylvania State University by researchers namely, Thomas A. Ryan, Barbara F. Ryan, Jr., and Brian L. Joiner in 1972.

Minitab came to the market with its first soft version called as Omni-tab it was a program or algorithm use for the research work in the NIST ; the coding and the manual of omni-tab was printed in 1986.

Minitab is owned by Minitab Inc, it is a privately owned company with its headquarters situated in the State College of Pennsylvania, with its other branches in Coventry, England, Paris, France and Sydney, Australia.

In the present scenario, mini-tab is used in close usage and induction of other soft wares which are also optimizers and can be used to bring better results.

Minitab 17, is the new version of this software, and is available in 8 languages: Japanese, Korean, Portuguese English, german , french, Simplified Chinese, & Spanish.

Minitab Inc. sells two other products that come in handy while using Minitab 17:

1. Quality Trainer: an eLearning file that allows in understanding the statistical tools.
2. Quality Companion 3: a tool integrated to the system so that it can be used to involve both the six sigma and the lean manufacturing so as to use the product in all types of fields and make it an all round.

Chapter 4 DATA-ANALYSIS

The design table to be used was made by deciding the values of the parameters to be set in the experiment. Namely, the diameter of drill, feed rate and speed of drill or rpm were set accordingly. The values were defined on basis of the values available in the machine so as to perform the experiment and various levels were selected as shown in table 5.

Table 5: levels of the factors of parameters in drilling

Drill diameter(mm)	Feed rate (mm/rev)	Speed (rpm)
8	0.12	150
10	0.2	220
12	0.3	440

The values or the factors were thus defined and with help of minitab the rsm value table was then generated which would set the values or the order of the readings in the experiment.

CCD:-

Nos of Factor: 3 Replicas: 1

Total runs: 20

Number of Base blocks: 1

Total number of blocks: 1

2-level factorial: Full factorial

Number of Cube points: 8

Center points taken in the cube: 6

Number of Axial points taken: 6

Center points taken in axial: 0

Alpha: 1

Design Table (randomized)

Table 6 : the design table

Trial	Block	d	f	s
1	1	0	0	0
2	1	0	0	0
3	1	-1	1	-1
4	1	0	0	-1
5	1	-1	1	1
6	1	0	0	0
7	1	0	-1	0
8	1	-1	0	0
9	1	0	0	0
10	1	0	0	0
11	1	0	0	1
12	1	0	0	0
13	1	1	0	0
14	1	0	1	0
15	1	1	-1	-1
16	1	1	1	-1
17	1	1	-1	1
18	1	-1	-1	-1
19	1	-1	-1	1
20	1	1	1	1

After the process of drilling the record table obtained was as shown in table 7:

Table 7 : recorded data during drilling process

Nos.	Drill diameter	Feed	Speed	Thrust	Torque
	(mm)	Rate(mm/rev)	(rpm)	(kg)	(Kg. M)
1	10	0.2	220	427	1.2
2	10	0.2	220	420	1.2
3	8	0.3	150	348	1.1
4	10	0.2	150	331	1.4
5	8	0.3	440	377	1.6
6	10	0.2	220	332	1.4
7	10	0.12	220	246	0.8
8	8	0.2	220	203	0.8
9	10	0.2	220	312	1.3
10	10	0.2	220	315	1.4
11	10	0.2	440	440	1.2
12	10	0.2	220	335	1.3
13	12	0.2	220	429	1.7
14	10	0.3	220	452	1.6

15	12	0.12	150	299	1.4
16	12	0.3	150	634	2.6
17	12	0.12	440	268	1.4
18	8	0.12	150	170	0.5
19	8	0.12	440	163	0.7
20	12	0.3	440	819	2.4

After the process of the measuring the roughness for the corresponding experiments the value of roughness obtained for the specimen was recorded accordingly as shown in

table 8 :

Table 8: final experimental data

Nos.	Drill diameter (mm)	Feed-Rate (mm/rev)	Speed(rpm)	Thrust (kg)	Torque (Kg.-M)	Surface Roughness µm
1	10	0.2	220	427	1.2	5.48
2	10	0.2	220	420	1.2	5.92
3	8	0.3	150	348	1.1	5.16
4	10	0.2	150	331	1.4	4.76
5	8	0.3	440	377	1.6	6.82
6	10	0.2	220	332	1.4	5.18

7	10	0.12	220	246	0.8	4.82
8	8	0.2	220	203	0.8	6.32
9	10	0.2	220	312	1.3	5.94
10	10	0.2	220	315	1.4	6.72
11	10	0.2	440	440	1.2	9.32
12	10	0.2	220	335	1.3	7.48
13	12	0.2	220	429	1.7	6.52
14	10	0.3	220	452	1.6	9
15	12	0.12	150	299	1.4	6.74
16	12	0.3	150	634	2.6	5.32
17	12	0.12	440	268	1.4	5.28
18	8	0.12	150	170	0.5	6.48
19	8	0.12	440	163	0.7	4.3
20	12	0.3	440	819	2.4	9.14

Optimal Design: d, f, s

Initial design produced by Sequential method

Initial design worked and improved by Exchange method

Response surface design obtained through D-optimality

Number of design points: 20

Number of design points changed in the process 1

Design points in optimal design: 10

Model terms available : A, B, C, AA, BB, CC, AB, AC, BC

Optimal Design

Row number of selected design points: 19, 15, 17, 8, 16, 3, 18, 7, 11, 5

Condition number: 5612.25

D-optimality (determinant of XTX): 8.04979E+19

Value of A-optimality (trace of inv(XTX)): 20549.5

Value of G-optimality (avg leverage/max leverage): 1

Value for V-optimality (average leverage): 1

Max. leverage: 1

Table 9: Matrix of data

Trial	D	F	s
19	8	0.12	440
15	12	0.12	150
17	12	0.12	440
8	8	0.2	220
16	12	0.3	150
3	8	0.3	150
18	8	0.12	150
7	10	0.12	220
11	10	0.2	440

5	8	0.3	440

The parameters thus after being defined were made constant for the process and the optimization was thus taken forward.

The design was then set and the graphs were obtained between different values depending upon the required values and considerations

Residual plots: The difference between a fitted value (ŷ) and its corresponding observed value (y) Is called the residual and the plot of the variable with the fitted value is called residual plot.

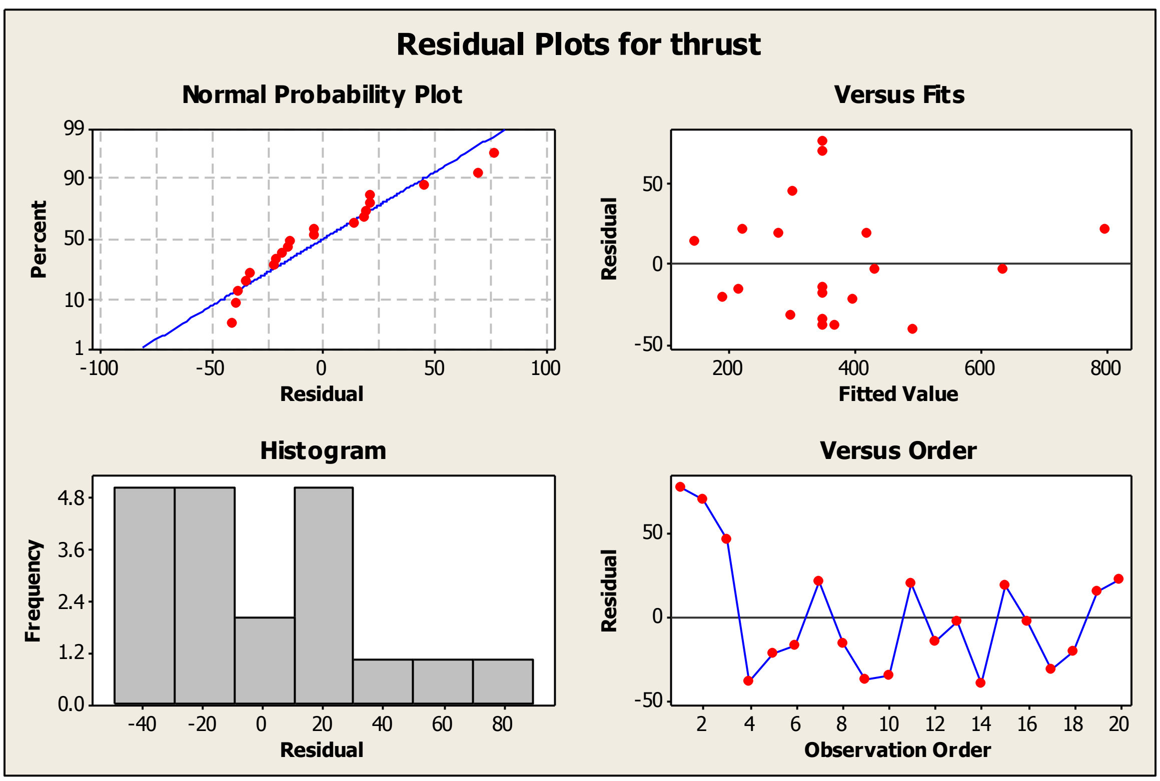

Figure 8 : residual plots for thrust

As stated in the fig.8. The straight line indicates the normal distribution of residuals.

Residuals are mostly varied in the range of -40 and the large residual frequency is low so the data and curves obtained are nearly approx. to the desired value.

Moreover with the observation order the residuals are coming to the zero error and are fitted perfectly than the starting residuals

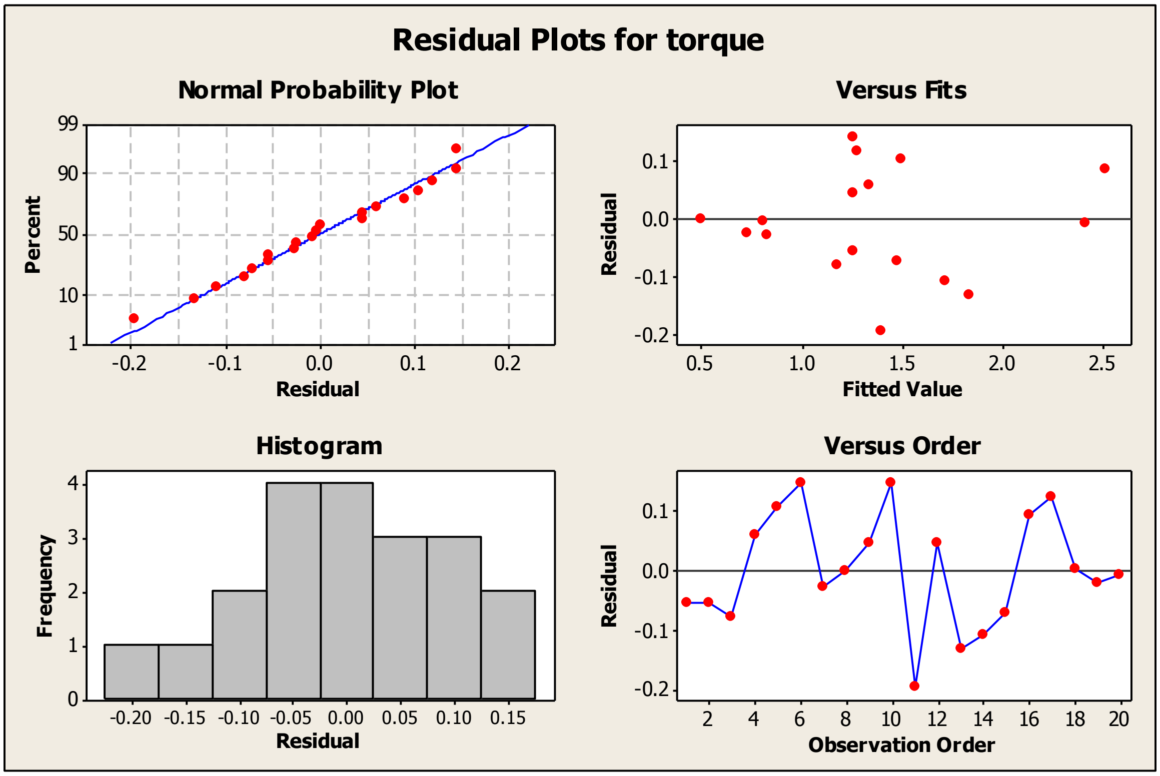

Figure 9 : residual plots for torque

As shown in fig 9. The torque residual is also in a normal distribution so it varies normally on both side of the mean.

With the help of histogram it can be easily seen that the residual are neatly in range of

-0.05 to 0.05 which is very small and it is a good sign of controlled responses.

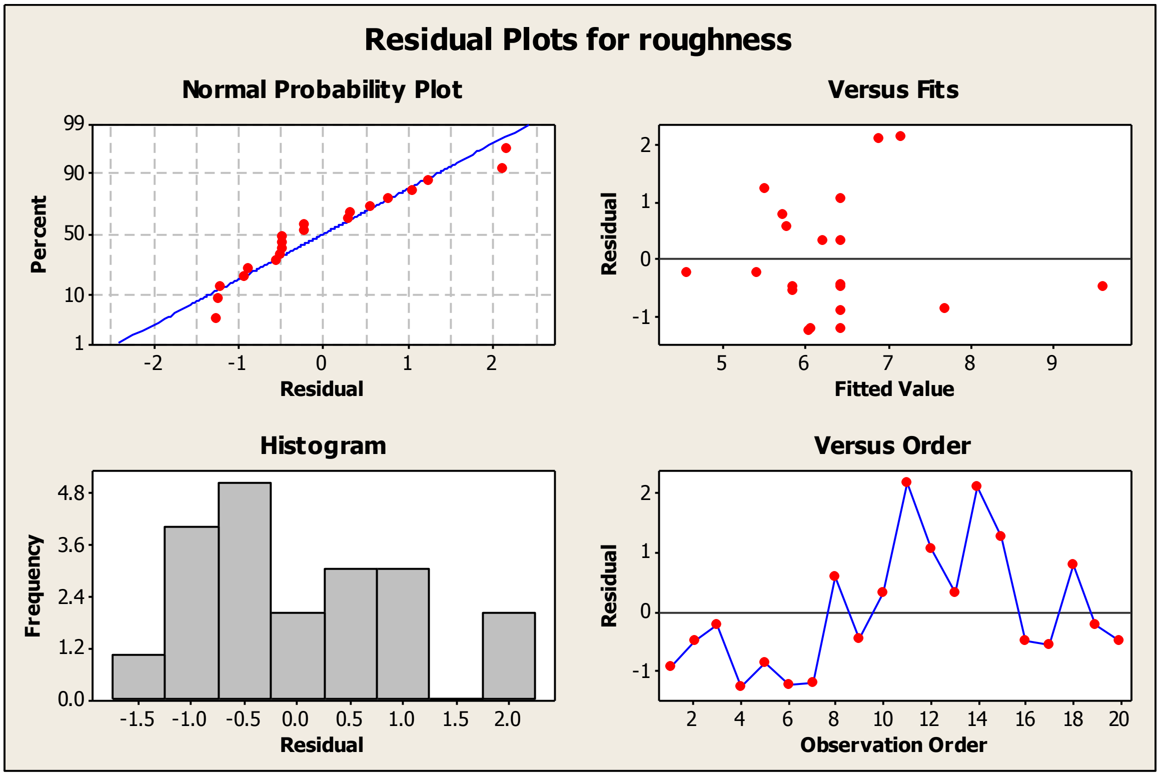

Figure 10: residual plots for roughness

Figure 10 clearly shows how roughness varies randomly with respect to the predictors set and it is max for -0.5 residual of roughness.

Main effects plot :

The main effects graph is nothing but actually a pictorial representation of the relationship of the input parameters with respect to the other results that are desired. Main effect draws the output variable mean or average value for every level of input set.

The pattern which is mostly obtained or pursued:

When the line is at 0° to the abscissa then there is relationship present in the variables. Each level of input variable effects the output variable in its own independent way, and output is different in all other input values.

When the graph obtained is a line and the line obtained is not at 0° to the abscissa then the value of output depends upon the variable and this causes the objective to draw the graph.

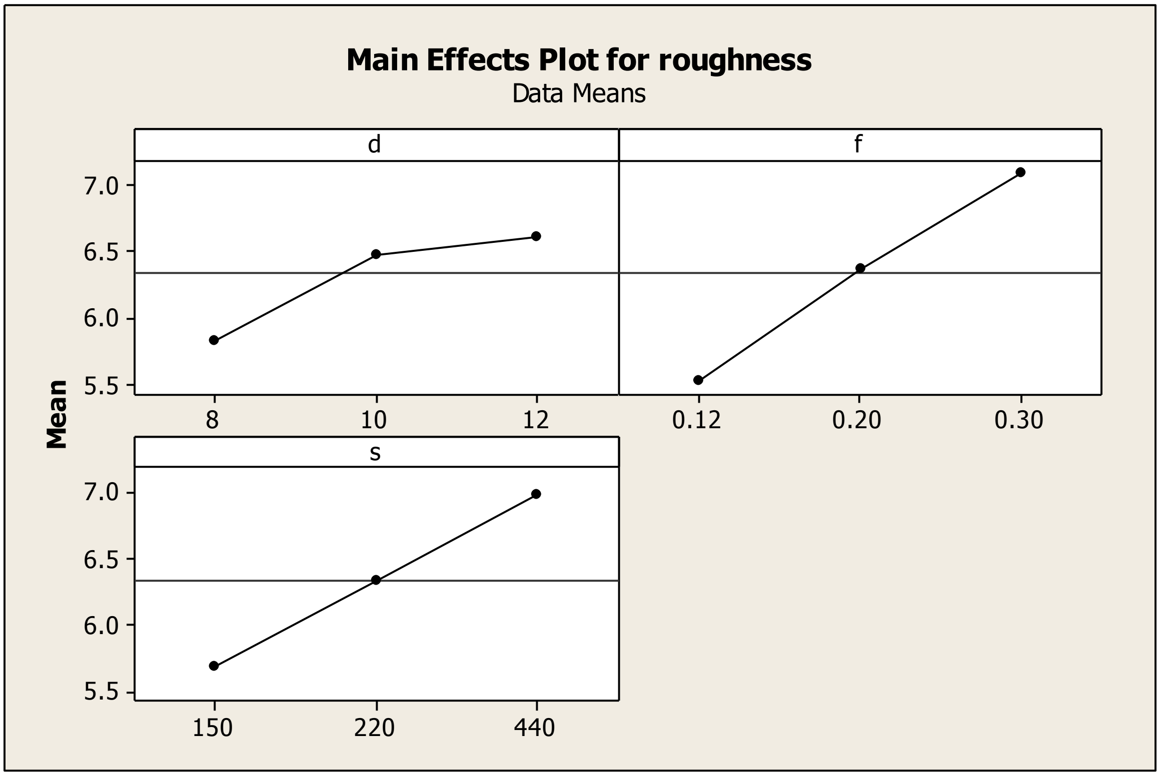

Figure 11 : main effects plot for roughness

From figure 11 :

With d:

The main effects plot with d clearly that roughness increases steeply with the diameter increase from 8mm to 10mm, but it increases at a slower rate while increasing from 10mm to 12mm.

The change in roughness is nearly constant in the feed and the speed values.

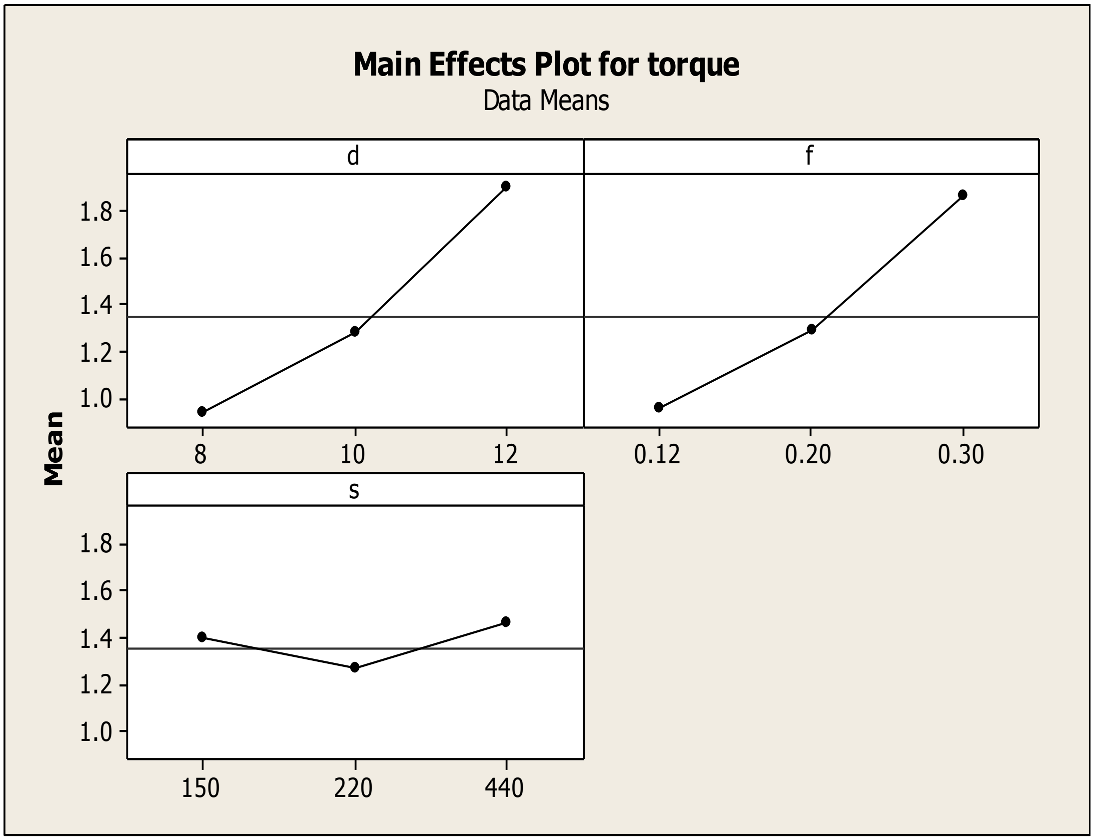

Figure 12 : main efects plot for torque

From figure 12. It can be clearly shown that torque varies at a high rate while moving from 10mm to 12mm with respect to the change from 8mm to 12mm.

Similar is the effect of f. While, with the s there is only a decrement while moving from 150rpm -220 rpm and again increase while moving from 220rpm -440 rpm.

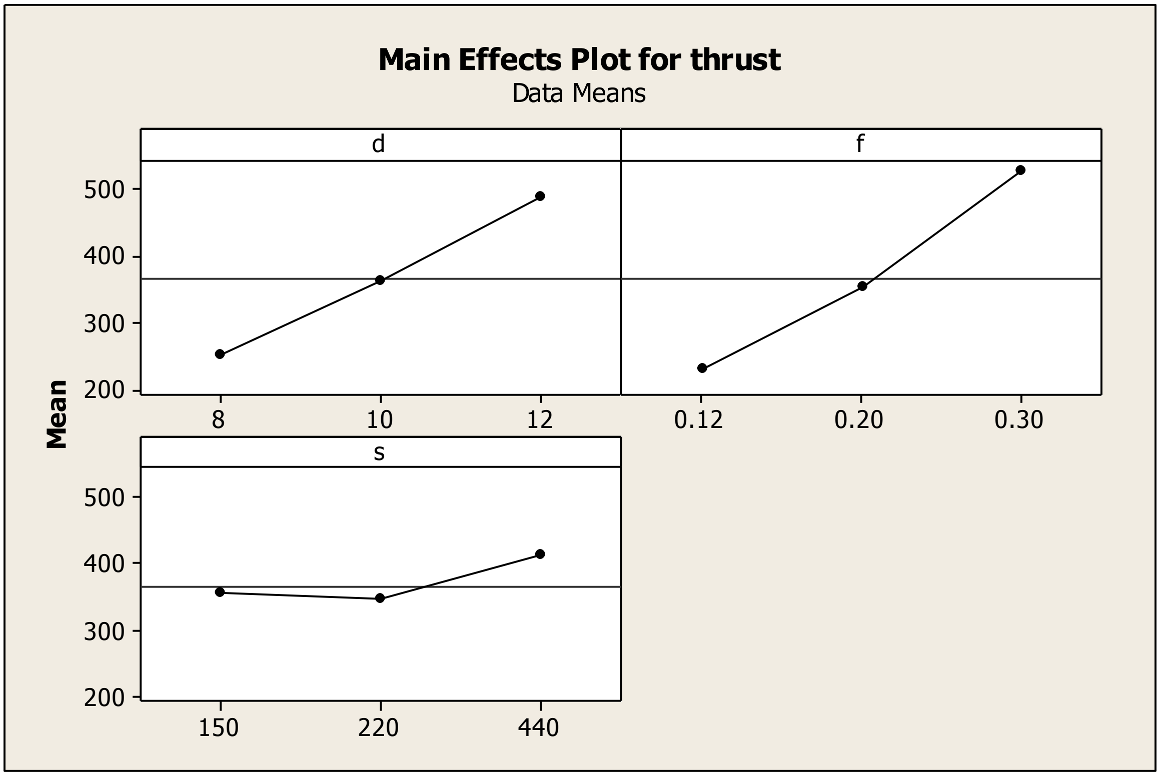

Figure 13 : main effects plot for thrust

Mean thrust varies constantly with respect to the d and f

But, with respect to s, the value is nearly same from 150rpm- 200rpm implying that both factors are nearly same in their effect on the mean.

Surface and contour plots:

Surface plots: 3D surface graph shows the 3-D relationship in two dimensions, with independent factors on the abscissa and the ordinate, and the result (z), the desired value is depicted by a smooth surface coined as a surface plot.

Contour plot: this graph can be defined as a map in which all the coordinates are measured correctly and then the values are plotted as the geographical map is made or drawn.

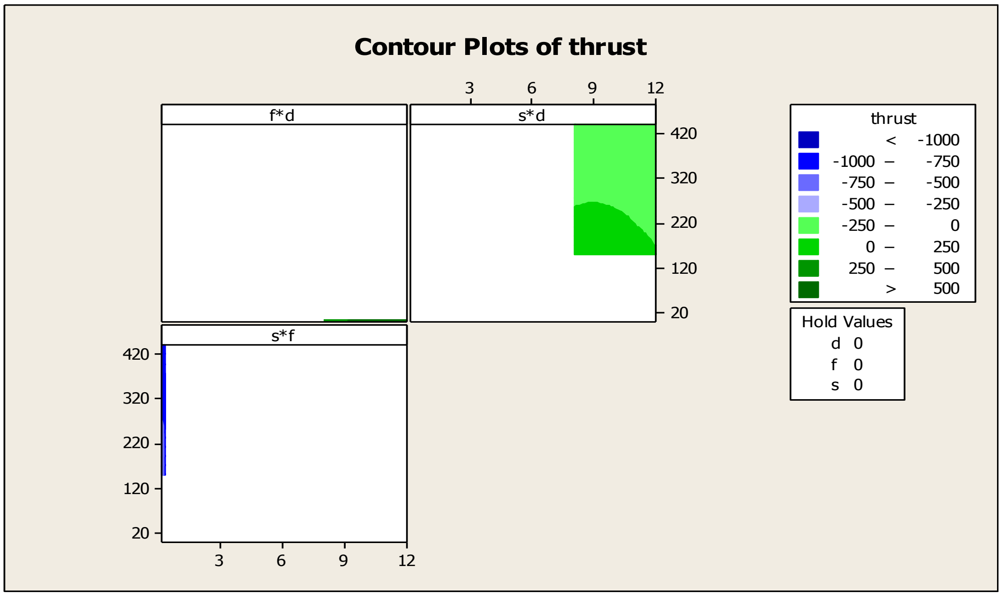

Figure 14 : contour plots for thrust

In figure 14 the various contours are shown in which the s*d graph has its area shown in different color coding. The different color coding designates the different ranges of thrust in the experiment obtained.

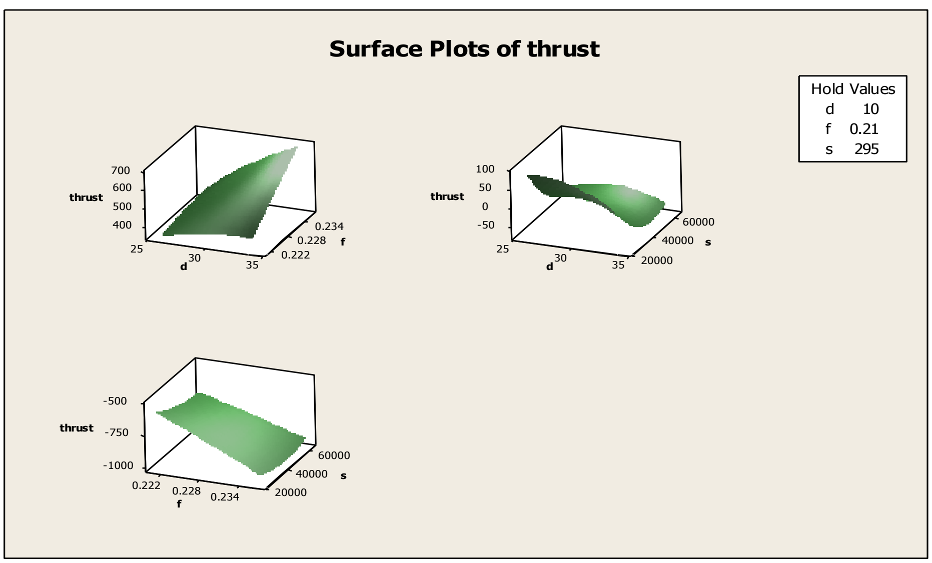

Figure 15 : surface plots for thrust

The surface plot in figure 15 depicts the curvature attained by the factors during drilling.

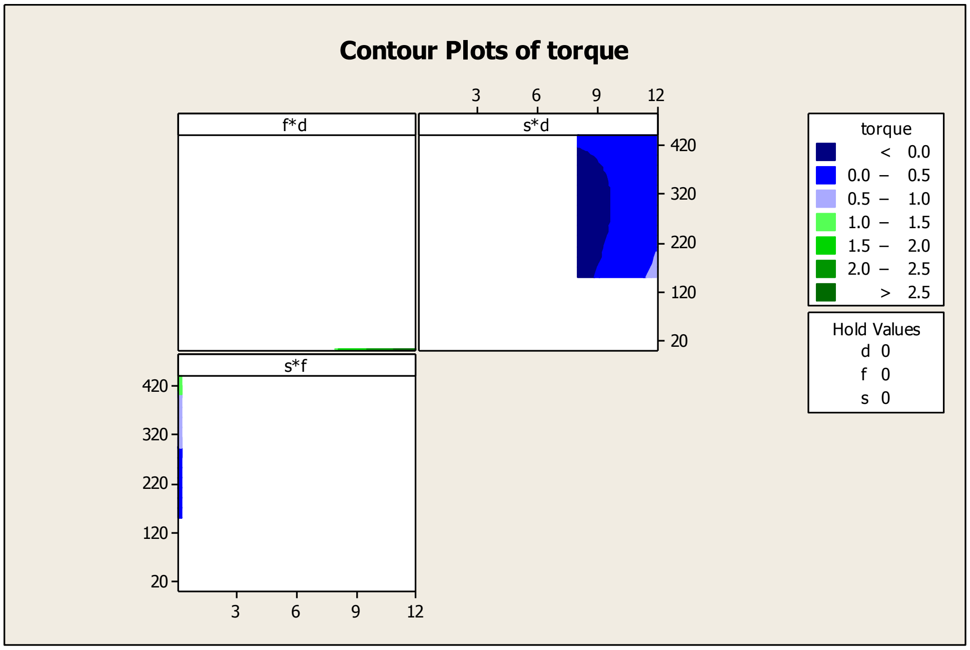

Figure 16: contour plots for torque

Figure 16 shows the different ranges of torque obtained in the experiments and the color coding indicates the various ranges in which the torque varies.

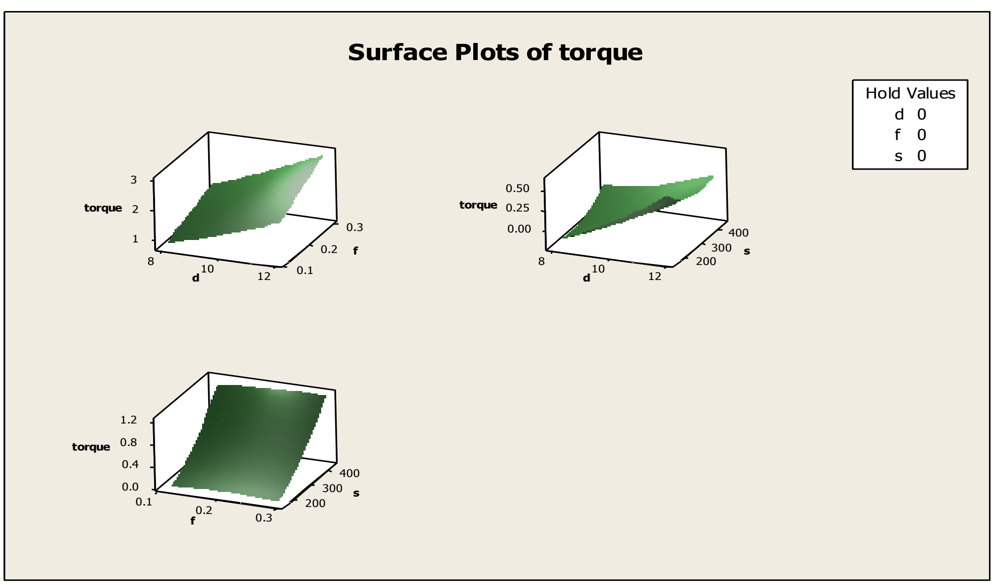

Figure 17 : surace plots for torque

The surface plot in figure 15 depicts the curvature attained by the factors during drilling in the torque with respect to different parameters. All are second order curves.

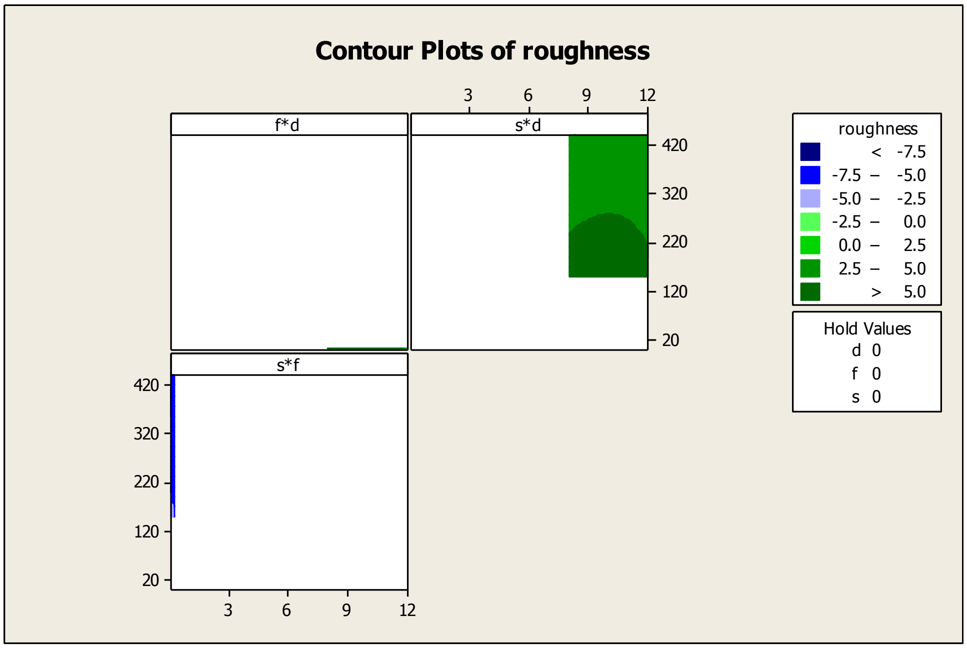

Figure 18: contour plots of roughness

In the Figure 18 the various plots are shown which depict the relation with which the roughness varies and it is clear from the graph that roughness ranges from (0-2.5)µm.

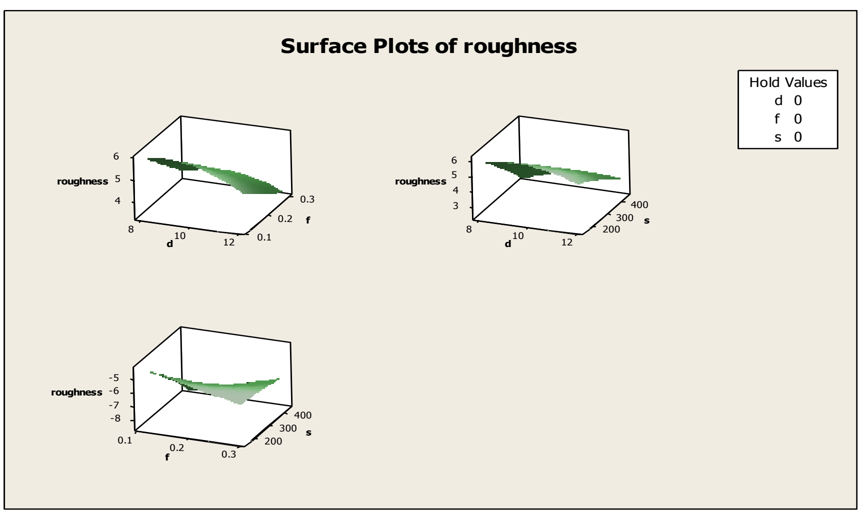

Figure 19: surface plots of roughness

The surface plots of roughness in figure 19 shows the variation of the roughness with respect to the different parameters in a second order curve.

Interaction plots:

When any factor is affected by the changes in any other factor then it is coined as interaction plot. This type of relationship can be seen effectively in the such plots.

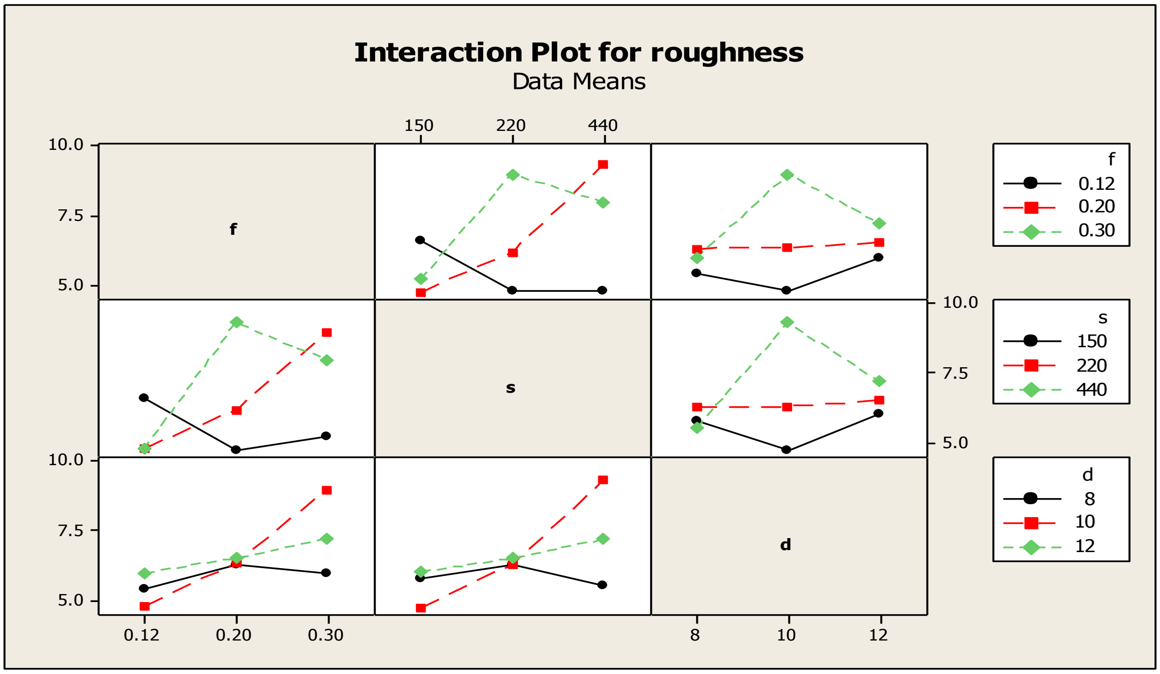

Figure 20 : interaction plots of roughness

Figure 20 shows that in the f graph with d and s in the first row shows that :

for minimum roughness

If s = 150 rpm best f = 0.2mm/rev ; if d= 8mm best f = 0.12 mm/rev

If s = 220rpm best f = 0.12 mm/rev ; if d=10mm best f=0.12 mm/rev

If s = 440rpm best f = 0.12 mm/rev ; if d=12mm best f=0.12 mm/rev

The s graph with d and f in the first row shows that : for minimum roughness

If f =0.12 mm/rev best s = (220, 440)rpm ; if d= 8mm best s = 440rpm

If f = 0.2 mm/rev best s = 150rpm ; if d=10mm best s=150rpm

If f = 0.3 mm/rev best s = 150rpm ; if d=12mm best s=150rpm

The d graph with s and f in the first row shows that : for minimum roughness

If s =150rpm best d = 10mm ; if f= 0.12 mm/rev best d = 10mm

If s = 220rpm best d = 10mm ; if f= 0.20 mm/rev best d=10mm

If s =440rpm best d = 8mm ; if f=0.30 mm/rev best d=8mm

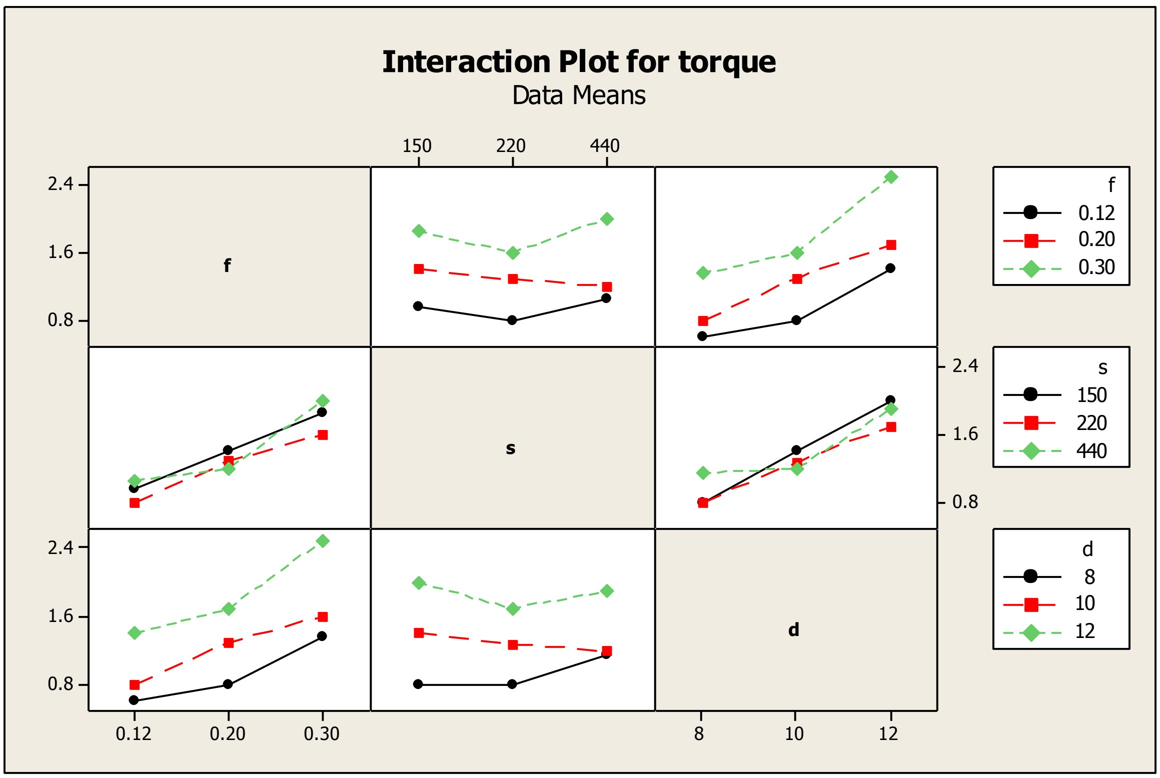

Figure 21 : interaction plots of torque

Figure 21 shows that with the f graph with d and s in the first row shows that :

for minimum torque

If s = 150rpm best f = 0.12 mm/rev ; if d= 8mm best f = 0.12 mm/rev

If s = 220rpm best f = 0.12 mm/rev ; if d=10mm best f=0.12 mm/rev

If s = 440rpm best f = 0.12 mm/rev ; if d=12mm best f=0.12 mm/rev

The s graph with d and f in the first row shows that : for minimum torque

If f =0.12 mm/rev best s = 220rpm ; if d= 8mm best s = (150,440)rpm

If f = 0.2 mm/rev best s = 440rpm ; if d=10mm best s=440rpm

If f = 0.3 mm/rev best s = 220rpm ; if d=12mm best s=220rpm

The d graph with s and f in the first row shows that : for minimum torque

If s =150rpm best d = 8mm ; if f= 0.12 mm/rev best d = 8mm

If s = 220rpm best d = 8mm ; if f= 0.20 mm/rev best d=8mm

If s =440 best d = 8,10 ; if f=0.30 mm/rev best d=8

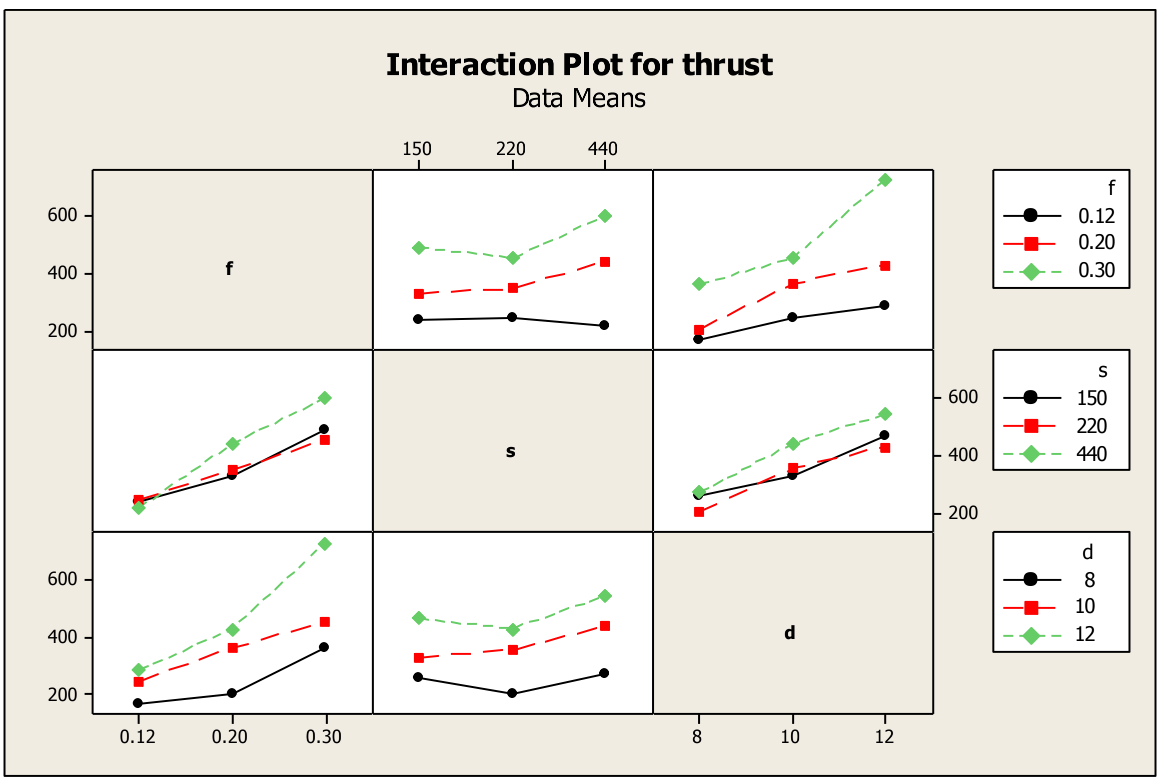

Figure 22 : interaction plots of thrust

From figure 22 the f graph with d and s in the first row shows that :

for minimum thrust

If s = 150rpm best f = 0.12 mm/rev ; if d= 8mm best f = 0.12 mm/rev

If s = 220rpm best f = 0.12 mm/rev ; if d=10mm best f=0.12 mm/rev

If s = 440rpm best f = 0.12 mm/rev ; if d=12mm best f=0.12 mm/rev

The s graph with d and f in the first row shows that : for minimum thrust

If f =0.12 mm/rev best s = (220, 440,150)rpm ; if d= 8mm best s = 220rpm

If f = 0.2 mm/rev best s = 150rpm ; if d=10mm best s=150rpm

If f = 0.3 mm/rev best s = 220rpm ; if d=12mm best s=220rpm

The d graph with s and f in the first row shows that : for minimum thrust

If s =150rpm best d = 8mm ; if f= 0.12 mm/rev best d = 8mm

If s = 220rpm best d = 8mm ; if f= 0.20 mm/rev best d=8mm

If s =440rpm best d = 8mm ; if f=0.30 mm/rev best d=8mm

CONTOUR PLOTS: These plots depict the variation of the parameters with respect to the other variables and show the responses on the area graph.

Contour plots of thrust , torque and roughness with f and d

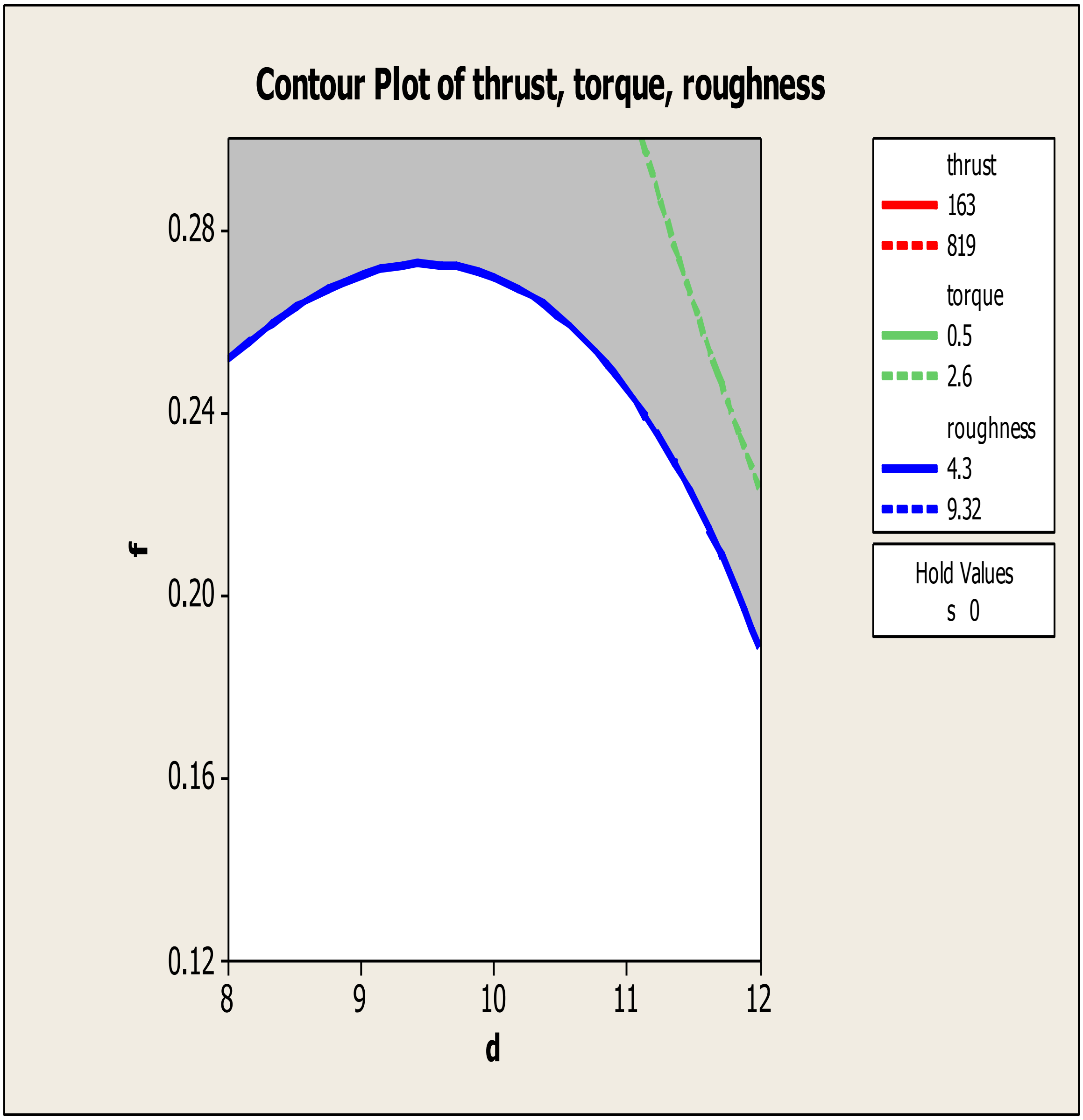

Figure 23: contour plots with f and d

White shaded region in the figure 23 is the region in which if the feed and drill diameter if kept than the three responses would be in the range as described in the graph particulars. This value is valid for speed of 220 rpm.

Contour plots of thrust , torque and roughness with s and d

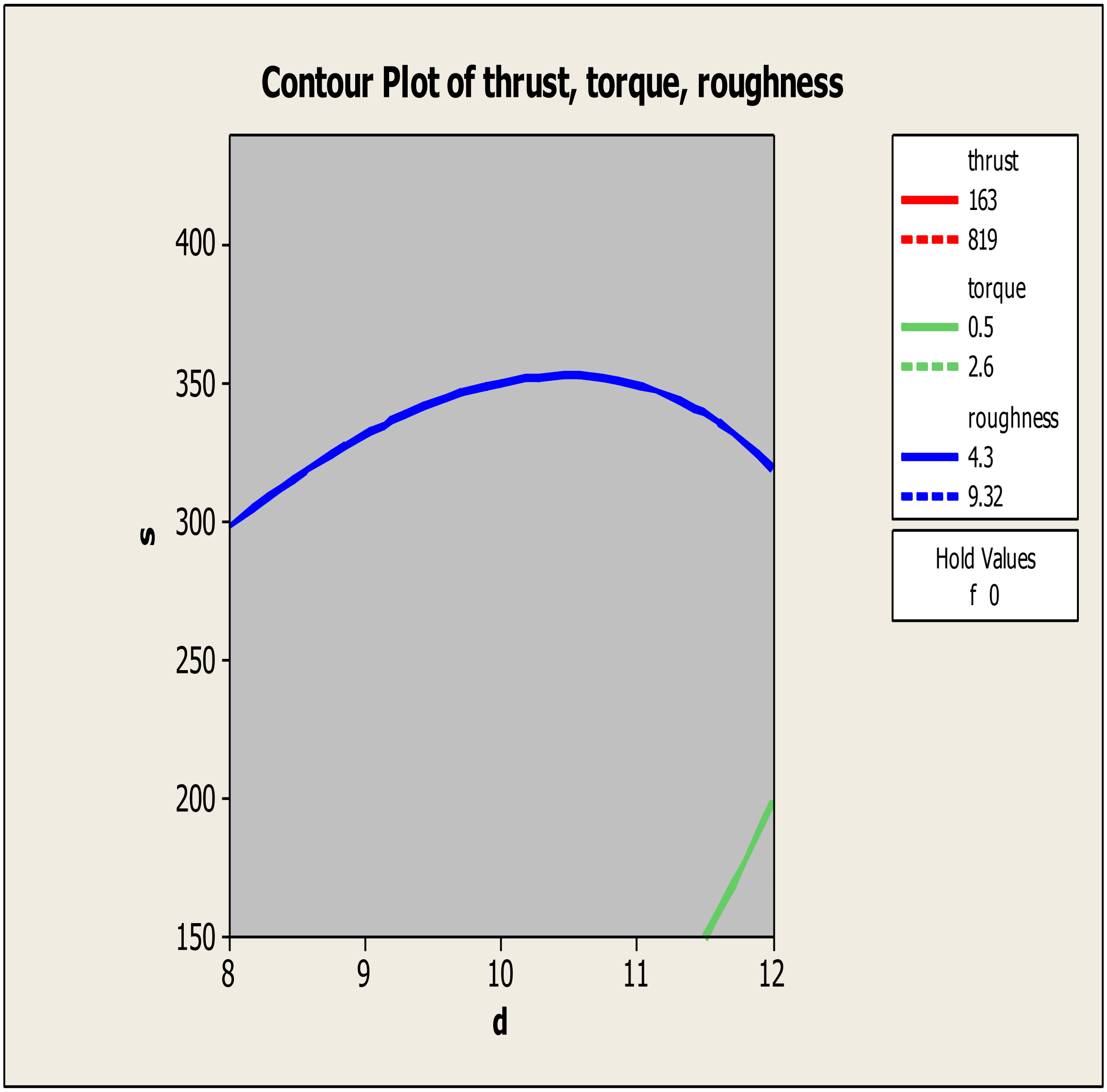

Figure 24 : contour plots with s and d

As seen from the graph area is between the s and d and has f=0 which implies that f=0.2 mm/rev.

The region above roughness line=4.3 in figure 24 is having all parameters as low which implies clearly that in this region the values are below the given parameters and thus the area is suitable for the drilling.

Contour plots of thrust , torque and roughness with s and f

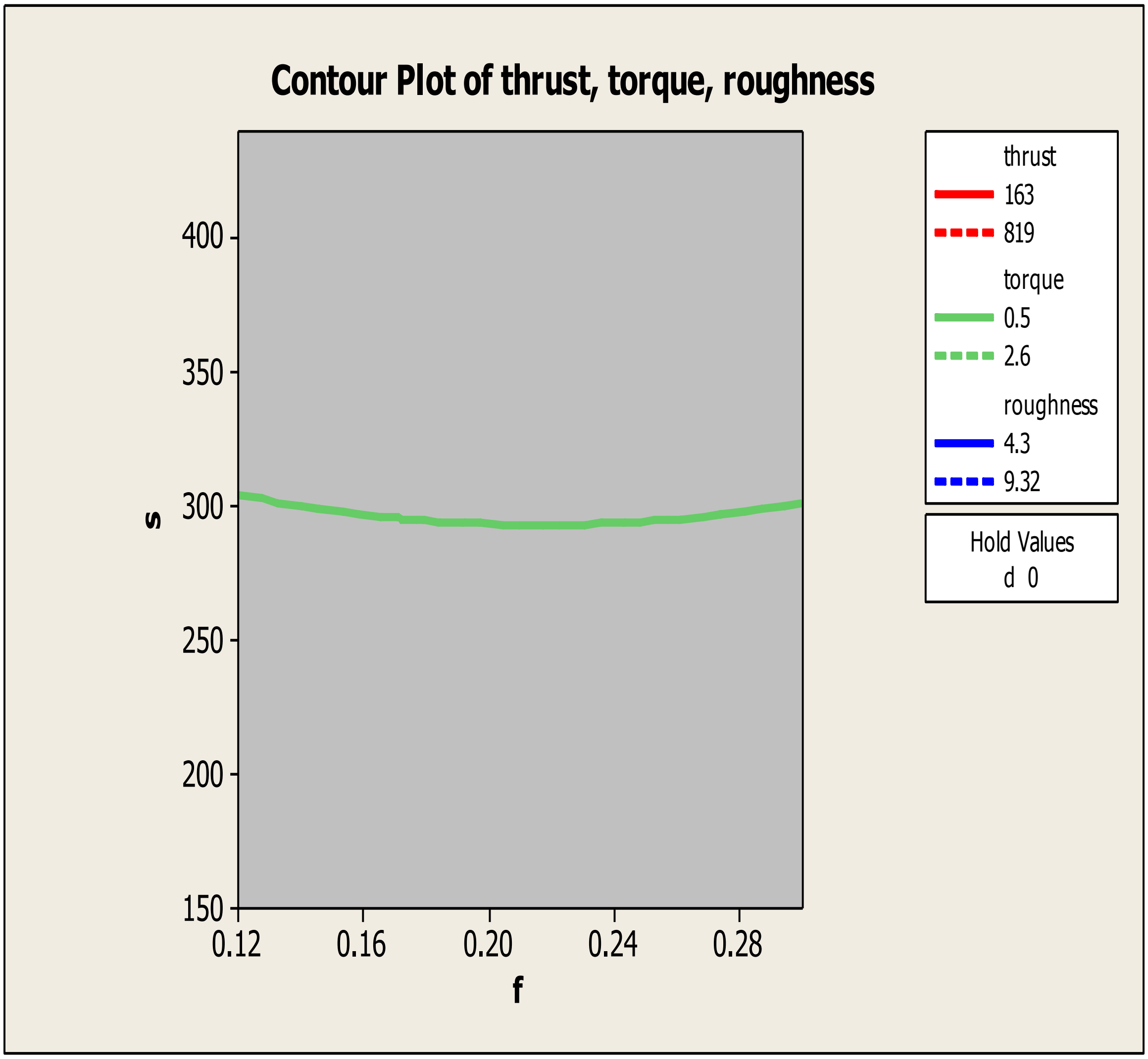

Figure 25: contour plots with s and f

Similarly as in above graph the feasible region is not available in the figure 25 but the region is low in the contour below the line of torque=0.5 while it is feasible above the same line and drill diameter is kept constant at 8mm.

Response Optimization

Parameters

Table 10 : target values table

	Goal	Lower	Target	Upper	Weight	Importance
Thrust	Target	163.0	500.0	819.0	1	1
Torque	Target	0.5	1.5	2.6	1	1
Roughness	Target	4.3	6.0	9.32	1	1

Starting point

Drill dia. = 8 mm

Feed rate = 0.12 mm/rev

Speed = 150 rpm

The optimal plot acts as the reference point for the graph — it can be modified for the settings interactively to obtain different responses. For the factorial and response surface designs, it is possible to adjust the factor levels. Reasons for changing these input variable settings in the optimization plot are varied but most important are:

1. To find out the input factor value with a higher optimized value
2. To find out cheap input factor settings with near optimized values.
3. To find the ability of response character for the changes in the design variables.
4. To substantiate the predicted outcomes for an input factor setting of desire.
5. To find the input factor start up values in the area near the local solution.

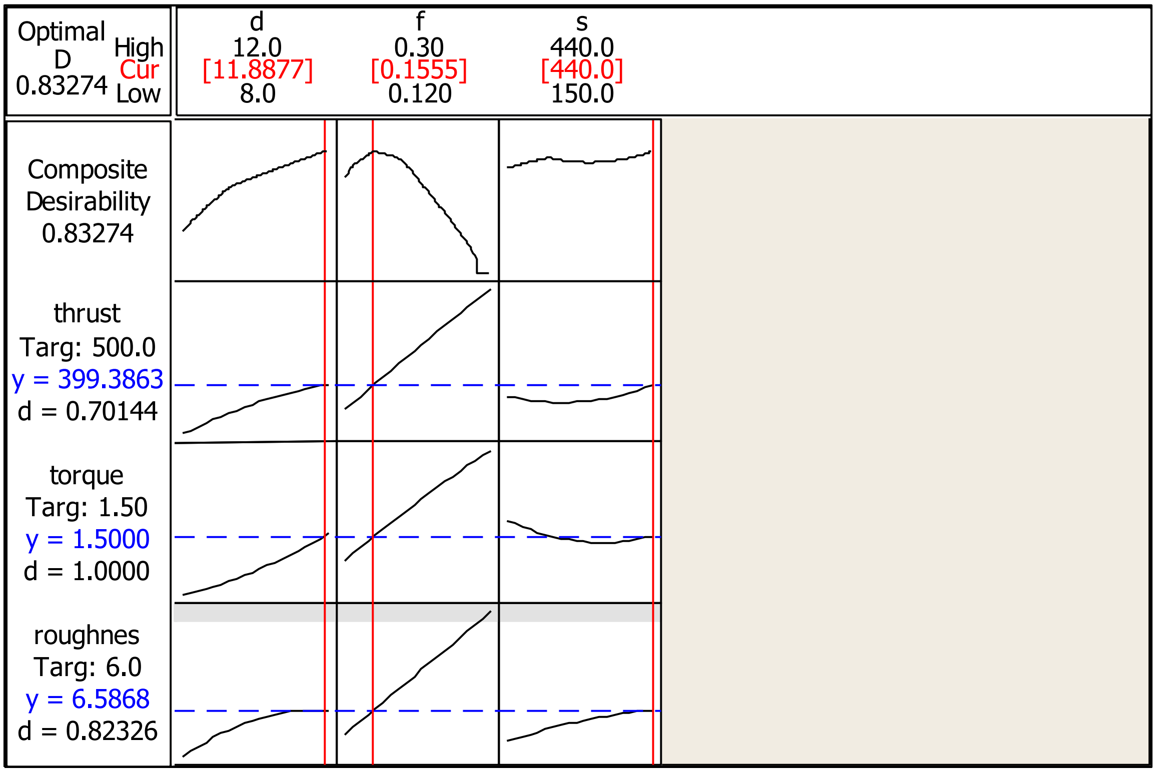

Figure 26 : optimized value for desired result

Predicted Responses from figure 26 :

Thrust = 399.386 , desirability = 0.701443

Torque = 1.500 , desirability = 1.000000

Roughness = 6.587 , desirability = 0.823258

Error in thrust from desired value = 500-399.386 = 100.614

Error in torque from desired value = 1.5-1.500 = 0

Error in roughness from desired value = 6-6.587 = .587

Composite Desirability = 0.832740

The optimality plot obtained in the process is aimed to achieve the desired parameters. But due to the approximation involved in the process the values obtained are near to the predictions.

At the prediction the setting is:

d = 11.8877 mm

f = 0.155478 mm/rev

s = 440.0 rpm

Here, the weights were given to all the responses according to the desired values and with importance or the priority level being set according to the desire the graph was obtained . The values obtained were in control and in accordance to the desired value. So it can be concluded that the RSM method is better method to analyze the process and surface roughness, torque and thrust depends upon the d, s, f and they can be controlled by controlling these factors.

Chapter 5 CONCLUSION

In this project various research papers were studied and accordingly the different methods to obtain the torque and thrust were analyzed to be taken in the consideration. It was assessed that surface roughness also depended upon the drill diameter along with other parameters such as feed and speed

The parameters studied were s, d, f and correspondingly the values were obtained for the thrust and torque in the drilling process.

CONCLUSIONS:

1. Drill diameter, speed of rotation, feed affect the surface roughness.
2. The torque, thrust and surface roughness are responses of d,s,f and they are controlled by them.
3. Contour and interaction plots clearly depict the interaction of the various parameters with respect to other parameters. For example:-
   speed with feed and drill diameter
   feed with speed and drill diameter
   drill diameter with speed and feed
   for the responses in the drilling process to be minimum or maximum as desired.
4. With help of the RSM cutting parameters can be obtained for the drilling at the desired cutting responses.

Optimized values for the drilling to have minimum thrust , torque and roughness are:

For roughness to be minimum the parameters to be taken in consideration are:

Drill dia	= 8 mm
Feed rate	= 0.12 mm/rev
Speed	= 150rpm

For torque to be minimum the parameters to taken in consideration are:

Drill dia	= 8mm
Feed rate	= 0.12mm/rev
Speed	= 220rpm

For thrust to be minimum the parameters to be taken in consideration are:

Drill dia	= 8mm
Feed rate	= 0.12mm/rev
Speed	= 220rpm

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