Optimization of Machining Parameters in Drilling of Al-6082

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

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IN
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ABSTRACT

In machining operations which influence cutting tool life, the vibration of machine tool play a vital role along with cutting parameters like Cutting Speed, Feed Rate & Depth of Cut. Thus, it becomes high imperative for the manufacturing industries to generate appropriate levels of process, parameters for estimating tool life. Recent advancement in cutting tool conditions monitoring had resulted in the use of multiple sensor for effective tool monitoring system.

The present work focuses on optimization of drilling machining parameters through the use of Taguchi method coupled with Grey Relational Analysis (GRA) for the minimization of the flank wear, cutting force, vibration and thus improving tool life. This is achieved by measuring the displacement data along the in-feed direction in drilling and applying Fast Fourier Transforms. The experimental trails are performed on Marine Grade (Al-6082) alloy in a CNC vertical machining center using Taguchi's L9 orthogonal array. The spindle speed, feed rate, depth of cut are selected as control factors and the experiments are conducted. The Analysis of variance (ANOVA) is employed to identify the most significant factor affecting the tool life. The optimal parameter values obtained during the study have been validated by a confirmation experiment.

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CHAPTER 1

INTRODUCTION

1.1 DRILLING OPERATION:

Drilling is a cutting process that uses a drill bit to cut a hole of circular cross section in solid materials. The drill bit is usually a rotary cutting tool, often multi-point. The bit is pressed against the work-piece and rotated at rates from hundreds to thousands of revolutions per minute. This forces the cutting edge against the work-piece, cutting off chips (swarf) from the hole as it is drilled.

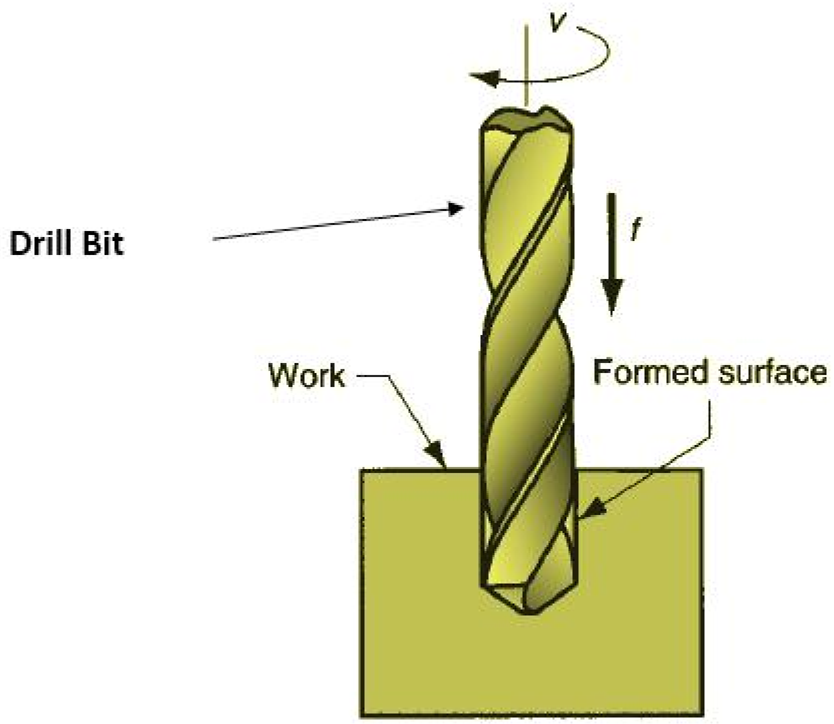


Fig (1.1) Drilling Operation

Surface finish produced by drilling may range from 32 to 500 micro inches. Finish cuts will generate surfaces near 32 micro inches, and roughing will be near 500 micro inches.

Cutting fluid is commonly used to cool the drill bit, increase tool life, increase speeds and feeds, increase the surface finish, and aid in ejecting chips. Application of these fluids is usually done by flooding the workpiece with coolant and lubricant or by applying a spray mist. In deciding which drill(s) to use it is important to consider the task at hand and evaluate which drill would best accomplish the task. There are a variety of drill styles that each serve a different purpose.

1.2 ADJUSTABLE CUTTING PARAMETERS IN DRILLING

The three primary factors in any basic drilling operation are speed, feed, and depth of cut. Other factors such as kind of material and type of tool have a large influence, of course, but these three are the ones the operator can change by adjusting the controls, right 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 drilling operation is the surface speed, or the speed at which the cutting tool moving. 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 drilling in m/min,

D is the drill diameter 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. 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:

The depth of cut in drilling is equal to one half of the drill diameter. If ‘d’ is the diameter of the drill, the depth of cut is d/2 mm.

1.3 Drill Nomenclature and Geometry:

The most important type of drill is the twist drill. The important nomenclature listed below and illustrated in the figure above.

1.3.1 Drill: A drill is an end-cutting tool for producing holes. It has one or more cutting edges, and flutes to allow fluids to enter and chips to be ejected. The drill is composed of a shank, body and point.

1.3.2 Shank: The shank is the part of the drill that is held and driven. It may be straight or tapered.

1.3.3 Tang: The tang is a flattened portion at the end of the shank that fits into a driving slot of the drill holder on the spindle of the machine.

1.3.4 Body: The body of the drill extends from the shank to the point, and contains the flutes. During sharpening, it is the body of the drill that is partially ground away.

1.3.5 Point: The point is the cutting end of the drill.

1.3.6 Flutes: Flutes are grooves that are cut or formed in the body of the drill to allow fluids to reach the point and chips to reach the workpiece surface. Although straight flutes are used in some cases, they are normally helical.

1.3.7 Land: The land is the remainder of the outside of the drill body after the flutes are cut. The land is cut back somewhat from the outside drill diameter to provide clearance.

1.3.8 Margin: The margin is a short portion of the land not cut away for clearance. It preserves the full drill diameter.

1.3.9 Web: The web is the central portion of the drill body that connects the lands.

1.3.10 Chisel edge: The edge ground on the tool point along the web is called the chisel edge. It connects the cutting lips.

1.3.11 Lips: The lips are the primary cutting edges of the drill. They extend from the chisel point to the periphery of the drill.

1.3.12 Axis: The axis of the drill is the centre line of the tool. It runs through the web and is perpendicular to the diameter.

1.3.13 Neck: Some drills are made with a relieved portion between the body and the shank. This is called the drill neck. In addition to these terms that define the various parts of the drill, there are a number of terms that apply to the dimensions of the drill, including the important drill angles. Among these terms are:

1.3.14 Length: Along with its outside diameter, the axial length of a drill is listed when the drill size is given. In addition, shank length, flute length and neck length are often used.

1.3.15 Body diameter clearance: The height of the step from the margin to the land is called the body diameter clearance.

1.3.16 Web thickness: The web thickness is the smallest dimension across the web. It is measured at the point unless otherwise noted. Web thickness will often increase in going up the body away from the point, and it may have to be ground down during sharpening to reduce the size of the chisel edge. This process is called "web thinning."

1.3.17 Helix angle: The angle that the leading edge of the land makes with the drill axis is called the helix angle. Drills with various helix angles are available for different operational requirements.

1.3.18 Point angle: The included angle between the drill lips is called the point angle. It is varied for different workpiece materials.

1.3.19 Lip relief angle: Corresponding to the usual relief angles found on other tools is the lip relief angle. It is measured at the periphery.

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 180ºC. 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.

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.

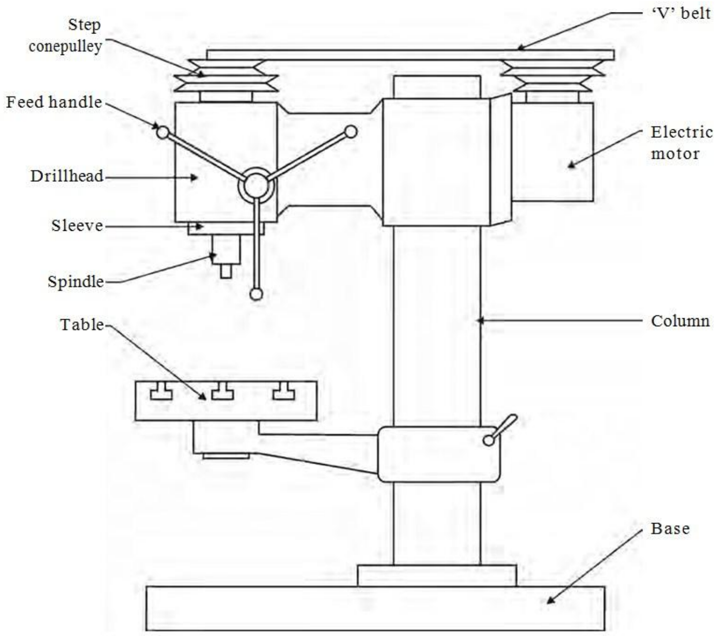
1.5 Drilling Machines:

1.5.1 Portable Drilling Machine:

Portable drilling machine can be carried and used anywhere in the workshop. It is used for drilling holes on workpieces in any position, which is not possible in a standard drilling machine. The entire drilling mechanism is compact and small in size and so can be carried anywhere. This type of machine is widely adapted for automobile built-up work. The motor is generally universal type. These machines can accommodate drills from 12mm to 18 mm diameter. Portable drilling machines are operated at higher speeds.

1.5.2 Sensitive Drilling Machine

It is designed for drilling small holes at high speeds in light jobs. High speed and hand feed are necessary for drilling small holes. The base of the machine is mounted either on a bench or on the floor by means of bolts and nuts. It can handle drills up to 15.5mm of diameter. The drill is fed into the work purely by hand. The operator can sense the progress of the drill into the work because of hand feed. The machine is named so because of this reason. A sensitive drilling machine consists of a base, column, table, spindle, drill head and the driving mechanism.



Sensitive drilling machine

Base – The base is made of cast iron and so can withstand vibrations. It may be mounted on a bench or on the floor. It supports all the other parts of the machine on it.

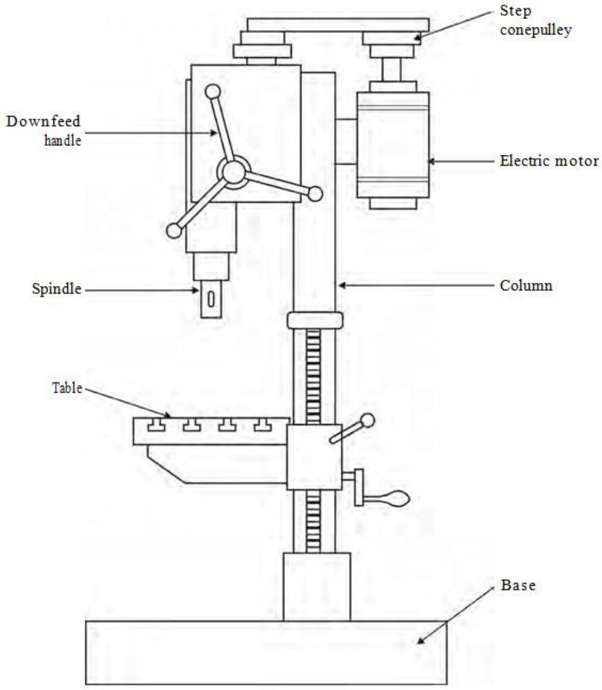
Column – The column stands vertically on the base at one end. It supports the work table and the drill head. The drill head has drill spindle and the driving motor on either side of the column.

Table – The table is mounted on the vertical column and can be adjusted up and down on it. The table has 'T'-slots on it for holding the workpieces or to hold any other work holding device. The table can be adjusted vertically to accommodate workpieces of different heights and can be clamped at the required position.

Drill head – Drill head is mounted on the top side of the column. The drill spindle and the driving motor are connected by means of a V-belt and cone pulleys. The motion is transmitted to the spindle from the motor by the belt. The pinion attached to the handle meshes with the rack on the sleeve of the spindle for providing the drill the required down feed. There is no power feed arrangement in this machine. The spindle rotates at a speed ranging from 50 to 2000 r.p.m.

1.5.3 Upright Drilling Machine

The upright drilling machine is designed for handling medium sized workpieces. Though it looks like a sensitive drilling machine, it is larger and heavier than a sensitive drilling machine. Holes of diameter up to 50mm can be made with this type of machine. Besides, it is supplied with power feed arrangement. For drilling different types of work, the machine is provided with a number of spindle speeds and feed.



Upright drilling machine

There are two different types of upright drilling machines according to the cross-section of the column and they are

1. Round column section upright drilling machine
2. Box column section upright drilling machine

The main parts of an upright drilling machine are: base, column, table and drill head.

Base – Base is made of cast iron as it can withstand vibrations set by the cutting action. It is erected on the floor of the shop by means of bolts and nuts. It is the supporting member as it supports column and other parts on it. The top of the base is accurately machined and has 'T'-slots. When large workpieces are to be held, they are directly mounted on the base.

Column – Column stands vertically on the base and supports the work table and all driving mechanisms. It is designed to withstand the vibrations set up due to the cutting action at high speeds.

Table – Table is mounted on the column and can be adjusted up and down on it. It is provided with 'T'-slots for workpieces to be mounted directly on it. Table may have the following adjustments

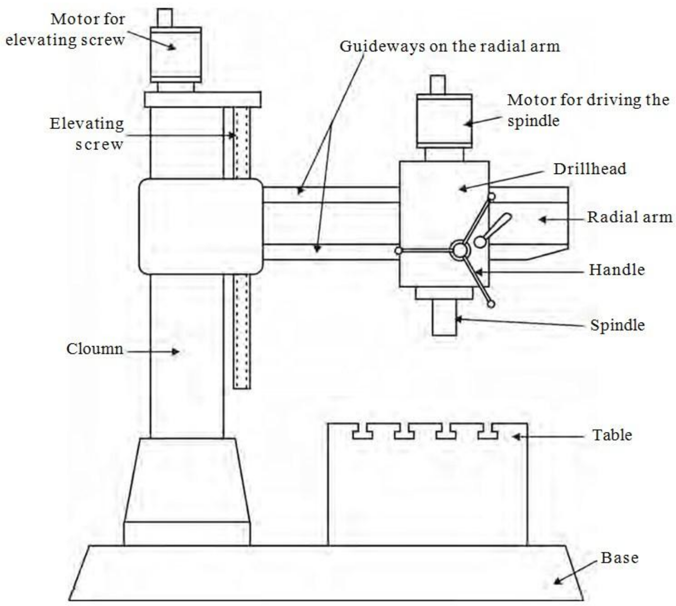
- Vertical adjustment obtained by the rack on the column and a pinion in the table
- Circular adjustment about its own axis

After the required adjustments are made, the table is clamped in position.

Drill head – The drill head is mounted on the top of the column. It houses the driving and feeding mechanism of the spindle. The spindle can be provided with hand or power feed. There are separate hand wheels for quick hand feed and sensitive hand feed. The handle is spring loaded so that the drill spindle is released from the work when the operation is over.

1.5.4 Radial Drilling Machine

The radial drilling machine is intended for drilling on medium to large and heavy workpieces. It has a heavy round column mounted on a large base. The column supports a radial arm, which can be raised or lowered to enable the table to accommodate workpieces of different heights. The arm, which has the drill head on it, can be swung around to any position. The drill head can be made to slide on the radial arm. The machine is named so because of this reason. It consists of parts like base, column, radial arm, drill head and driving mechanism.



Radial drilling machine

Base – The base is a large rectangular casting and is mounted on the floor of the shop. Its top is accurately finished to support a column at one end and the table at the other end. 'T'-slots are provided on it for clamping workpieces.

Column – The column is a cylindrical casting, which is mounted vertically at one end of the base. It supports the radial arm and allows it to slide up and down on its face. The vertical adjustment of the radial arm is affected by rotating a screw passing through a nut attached to the arm. An electric motor is mounted on the top of the column for rotating the elevating screw.

Radial arm – The radial arm is mounted on the column parallel to the base and can be adjusted vertically. The vertical front surface is accurately machined to provide guideways for the drill head. The drill head can be adjusted along these guideways according to the location of the work. In some machines, a separate motor is provided for this movement. The arm may be swung around the column. It can also be moved up and down to suit workpieces of different heights.

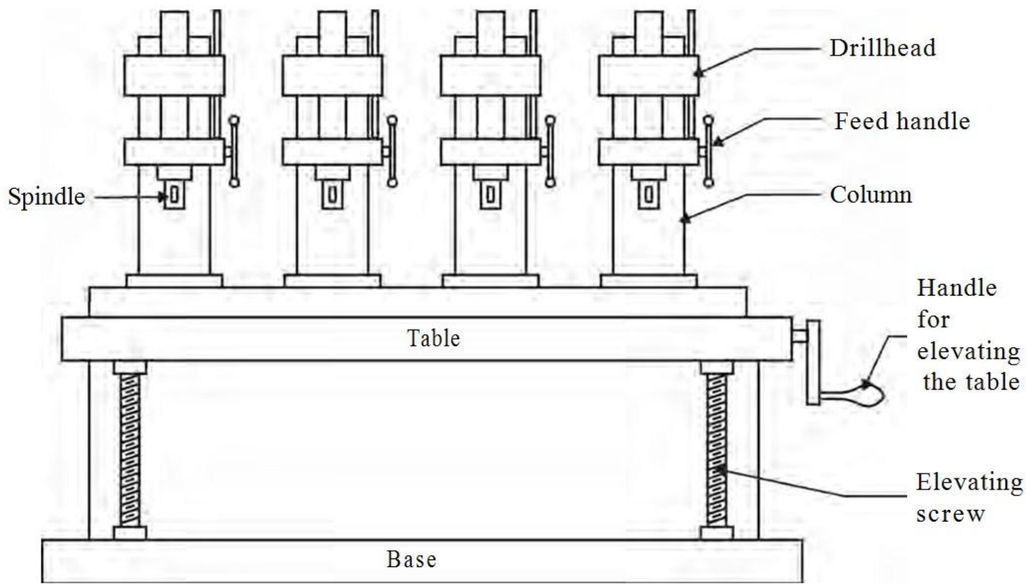
Drill head – The drill head is mounted on the radial arm and houses all mechanism for driving the drill at different speeds and at different feed. A motor is mounted on top of the drill head for this purpose. To adjust the position of drill spindle with respect to the work, the drill head may be made to slide on the guideways of the arm. The drill head can be clamped in position after the spindle is properly adjusted.

Universal radial drilling machine – It is a machine in which the spindle can be swivelled to any required angle in vertical and horizontal positions.

1.5.5 Gang Drilling Machine

Gang drilling machine has a long common table and a base. Four to six drill heads are placed side by side. The drill heads have separate driving motors. This machine is used for production work.

A series of operations like drilling, reaming, counterboring and tapping may be performed on the work by simply shifting the work from one position to the other on the work table. Each spindle is set with different tools for different operations.



Gang drilling machine

1.5.6 Multiple Spindle Drilling Machine

This machine is used for drilling a number of holes in a workpiece simultaneously and for reproducing the same pattern of holes in a number of identical pieces. A multiple spindle drilling machine also has several spindles. A single motor using a set of gears drives all the spindles. All the spindles holding the drills are fed into the work at the same time. The distances between the spindles can be altered according to the locations where holes are to be drilled. Drill jigs are used to guide the drills.

1.5.7 Deep Mole Drilling Machine

A special machine and drills are required to drill deeper holes in barrels of gun, spindles and connecting rods. The machine designed for this purpose is known as deep hole drilling machine. High cutting speeds and less feed are necessary to drill deep holes. A non- rotating drill is fed slowly into the rotating work at high speeds. Coolant should be used while drilling in this machine. There are two different types of deep hole drilling machines

1. Vertical type
2. Horizontal type

Chapter 2
Literature Review

Chapter 2

Literature Review

SUMESH A.S & MELVIN ELDHO SHIBU ,"Optimization of drilling parameters for minimum surface roughness using Taguchi method" Journal of mechanical and civil engineering, Pages 12-20

The present work is to optimize process parameter such as cutting speed, feed, and drill diameter. Taguchi methods are widely used for design of experiments and analysis of experimental data for optimization of processing conditions. The research contributions are classified into methodology for investigation and analysis, input processing conditions and response variables. This paper focuses on the optimization of drilling parameters using the Taguchi technique to obtain minimum surface roughness (Ra). A number of drilling experiments were conducted using the L9 orthogonal array on a radial drilling machine. The experiments were performed on cast iron using HSS twist drills. Analysis of variance (ANOVA) was employed to determine the most significant control factors affecting the surface roughness. The cutting speed, feed rate and drill diameter were selected as control factors. After the nine experimental trials, it was found that the drill diameter was the most significant factor for the surface roughness. The results of the confirmation experiments showed that the Taguchi method was notably successful in the optimization of drilling parameters for better surface roughness. Commercial software package MINITAB17 is used for performing the analysis.

M.BALAJI & B.S.N.MURTHY "Optimization of drilling parameters for drilling of TI-6Al-4V based on surface roughness, flank wear and drill vibration "Measurement, volume114 , january 2018,pages 332-339

In drilling of TI-6Al-4V alloy, drill bits are subjected to chatter vibration and it causes poor surface finish and tool failure. In this study, effect of drilling parameters such as spindle speed, helix angle and feed rate on surface roughness, flank wear and acceleration of drill vibration velocity was investigated using Response Surface Methodology. A Laser Doppler Vibrometer (LDV) was used to measure vibration of drill bit in the form of Acousto Optic Emission (AOE) signal. And these signals were transformed into time domain with different time frequency zones using a high speed fast Fourier transformer. Experimental data were analyzed using Response Surface Methodology (RSM) to identify significant parameters on surface roughness, flank wear and acceleration of drill vibration velocity. A multi response optimization was performed to optimize drilling parameters for minimum surface roughness, flank wear and acceleration of drill vibration velocity. Optimum cutting parameters were found as 26.16 degrees of helix angle, 10.0 mm/min of feed rate and 600rpm of spindle speed.

SHASHANK MUDGAL VIMLESH KUMAR SONI, "Experimental Investigation and Optimization of Cutting Parameter Using GRA Method on Mild Steel", International Journal of Latest Technology in Engineering, management & applied sciences, volume 3, issue 7 ,pages 198-205.

In this process unwanted material is removed from the work-piece material by tool bit in the form of chip. Tool material should be hard than the work piece material. Surface roughness is the most important property of material which should be minimized but not on the behalf of material removal rate. Therefore a multi objective optimization technique is required for the optimization of surface roughness and material removal rate simultaneously. For fulfil this purpose grey relational analysis is used. in grey relational analysis, more than one response variables are converted into single response variable that is called as grey relational grade. Hence by the optimization of GRG, Ra and MRR both are optimised.

ASHVIN.J.MAKADIA & J.I.NANAVATI ,"Optimisation of machining parameters for turning operations based on response surface methodology", Measurement 46, december 2012 ,pages 1521-1529

Design of experiments has been used to study the effect of the main turning parameters such as feed rate, tool nose radius, cutting speed and depth of cut on the surface roughness of AISI 410 steel. A mathematical prediction model of the surface roughness has been developed in terms of above parameters. The effect of these parameters on the surface roughness has been investigated by using Response Surface Methodology (RSM). Response surface contours were constructed for determining the optimum conditions for a required surface roughness. The developed prediction equation shows that the feed rate is the main factor followed by tool nose radius influences the surface roughness. The surface roughness was found to increase with the increase in the feed and it decreased with increase in the tool nose radius. The verification experiment is carried out to check the validity of the developed model that predicted surface roughness within 6% error.

BALBIR SINGH & DEEPAK BYOTRA "Optimization of Machining Parameters in Turning Operation of EN13 Steel using Response Surface Methodology "International Journal of Engineering Technology, Management and Applied Sciences ,volume 3,march 2015,pages 648-655.

The most important factors in production are low cost, high quality product in short time. These can be achieved by selecting optimum level of machining parameters for machining of any material in mass production. In this paper will showcase the experimental investigation of EN13 steel for turning operation. The processing parameters that are chosen are cutting speed, feed rate and depth of cut and these are used to inquire about the material removal rate (MRR) of EN13 steel. Experiment is designed on the basis of Central Composite Rotatable Design (CCRD) using Response surface methodology (RSM). Mathematical model is developed between process parameters and MRR. The significance of processes parameters and adequacy of model are analyzed using analysis of variance (ANOVA). Interaction effects between the parameters and MRR are analyzed by various three dimensional graphical representation. Further optimization of machining parameters for turning operation is carried out. Confirmatory experiment is performed on the optimal values.

P.JAYARAMAN & L.MAHESH KUMAR "Multi-response Optimization of Machining Parameters of Turning AA6063 T6 Aluminium Alloy using Grey Relational Analysis in Taguchi Method ", Procedia engineering volume 97 ,2014 ,pages 197-204.

This paper presents an approach for the optimization of machining parameters on turning of AA 6063 T6 aluminium alloy with multiple responses based on orthogonal array with grey relational analysis. Experiments are conducted on AA 6063 T6 aluminium alloy. Turning tests are carried out using uncoated carbide insert under dry cutting condition. Turning parameters such as cutting speed, feed rate and depth of cut are optimized considering the multiple responses such as surface roughness (Ra), roundness (Ø) and material removal rate (MRR). A grey relational grade(GRG) is determined from the grey analysis. Optimum levels of parameters have been identified based on the values of grey relational grade and then the significant contribution of parameters is determined by ANOVA. To validate the test result, confirmation test is performed.

Summary of literature review:

By the review of all these projects it is obvious that a lot of work is put into the study of effect of machining parameters in different process on various materials. Thus in the present paper optimization of machining parameters in drilling of aluminium metal has been studied

Chapter 3
Design Of Experiments

CHAPTER 3

DESIGN OF EXPERIMENTS

3.1 Design of experiments:

3.1.1 Overview:

DOE (Design of Experiments) helps you investigate the effects of input variables(factors) on an output variable(response) at the same time. These experiments consist of series of runs, or tests, in which purposeful changes are made to the input variables. Data are collected in each run. You use DOE to identify the process conditions and product components that effect quality, and then determine the factors setting the optimize results.

Mini tab offers four types of designs: factorial designs, response surface designs, mixture designs, and Taguchi designs (also called Taguchi robust designs). The steps you follow in Minitab to create, analyse, and visualise a designed experiment are similar for all types. After you perform the experiment and enter the results. This chapter demonstrates the typical steps to create and analyse a factorial design. You can apply these steps to any design that you create in Minitab.

Minitab DOE commands include the following features:

- Catalogues of designed experiments to help you create a design.
- Automatic creation and storage of your design after you specify its properties.
- Display and storage of diagnostic statics to help you interpret the results.
- Graphs to help you interpret and present the results.

3.1.2 Types of Design Experiments:

Before you can enter or analyse DOE data in Minitab, you must first create a designed experiment in the worksheet. Minitab offers a variety of designs.

Factorial:

Includes 2-level full designs, 2-level fractional designs, split-plot designs, and Plackett-Burman designs.

Response Surface:

Includes central composite designs and Box-Behnken designs.

Mixture:

Includes simplex centroid designs, simplex lattice designs, and extreme vertices designs.

Taguchi:

Includes 2-level designs, 3-level designs, 4-level designs, 5-level designs, and mixed level designs.

You choose the appropriate design based on the requirements of your experiment.

Choose the design from the Start > DOE menu. You can also open the appropriate toolbar by choosing Tools > Toolbars. After you choose the design and its features, Minitab creates the design and stores in the worksheet.

In this experiment we used Taguchi's method.

Taguchi methods are statistical methods, or sometimes called robust design methods, developed by Genichi Taguchi to improve the quality of manufactured goods, and more recently also applied to engineering, biotechnology, marketing and advertising. Professional statisticians have welcomed the goals and improvements brought about by Taguchi methods, particularly by Taguchi's development of designs for studying variation, but have criticized the inefficiency of some of Taguchi's proposals.

Taguchi's work includes three principal contributions to statistics:

- A specific loss function
- The philosophy of off-line quality control; and
- Innovations in the design of experiments.

Taguchi's use of loss functions Edit

Taguchi knew statistical theory mainly from the followers of Ronald A. Fisher, who also avoided loss functions. Reacting to Fisher's methods in the design of experiments, Taguchi interpreted Fisher's methods as being adapted for seeking to improve the mean outcome of a process. Indeed, Fisher's work had been largely motivated by programmes to compare agricultural yields under different treatments and blocks, and such experiments were done as part of a long-term programme to improve harvests.

However, Taguchi realised that in much industrial production, there is a need to produce an outcome on target, for example, to machine a hole to a specified diameter, or to manufacture a cell to produce a given voltage. He also realised, as had Walter A. Shewhart and others before him, that excessive variation lay at the root of poor manufactured quality and that reacting to individual items inside and outside specification was counterproductive.

He therefore argued that quality engineering should start with an understanding of quality costs in various situations. In much conventional industrial engineering, the quality costs are simply represented by the number of items outside specification multiplied by the cost of rework or scrap. However, Taguchi insisted that manufacturers broaden their horizons to consider cost to society. Though the short-term costs may simply be those of non-conformance, any item manufactured away from nominal would result in some loss to the customer or the wider community through early wear-out; difficulties in interfacing with other parts, themselves probably wide of nominal; or the need to build in safety margins. These losses are externalities and are usually ignored by manufacturers, which are more interested in their private costs than social costs. Such externalities prevent markets from operating efficiently, according to analyses of public economics. Taguchi argued that such losses would inevitably find their way back to the originating corporation (in an effect similar to the tragedy of the commons), and that by working to minimise them, manufacturers would enhance brand reputation, win markets and generate profits.

Such losses are, of course, very small when an item is near to negligible. Donald J. Wheeler characterised the region within specification limits as where we deny that losses exist. As we diverge from nominal, losses grow until the point where losses are too great to deny and the specification limit is drawn. All these losses are, as W. Edwards Deming would describe them, unknown and unknowable, but Taguchi wanted to find a useful way of representing them statistically. Taguchi specified three situations:

1. Larger the better (for example, agricultural yield);
2. Smaller the better (for example, carbon dioxide emissions); and

3. On-target, minimum-variation (for example, a mating part in an assembly).

The first two cases are represented by simple monotonic loss functions. In the third case, Taguchi adopted a squared-error loss function for several reasons:

- It is the first "symmetric" term in the Taylor series expansion of real analytic loss-functions.
- Total loss is measured by the variance. For uncorrelated random variables, as variance is additive the total loss is an additive measurement of cost.
- The squared-error loss function is widely used in statistics, following Gauss's use of the squared-error loss function in justifying the method of least squares.

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.

1.6.1 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.

1.6.2 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.

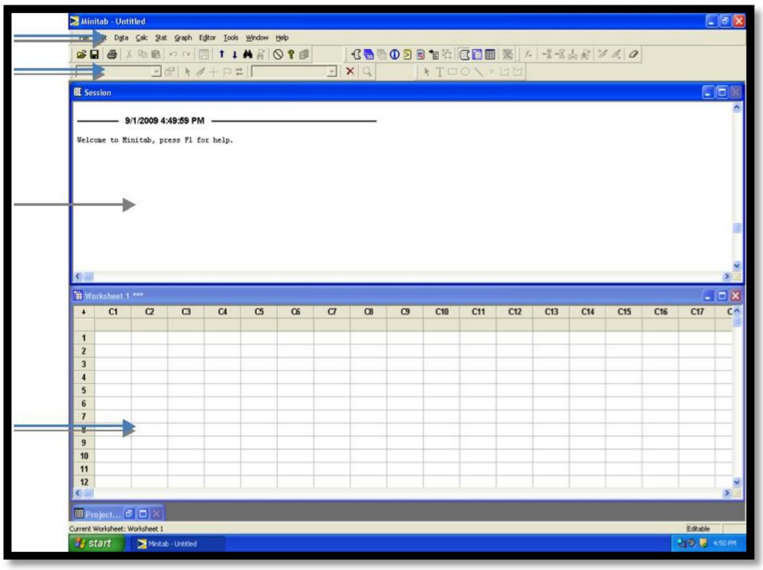


Fig 1.6: Environment in Minitab Software

Creating a Taguchi design in Minitab:

- Choose file > New > Project.
- Choose Stat > DOE > Taguchi > Create Taguchi design

When you create a design in Minitab, only two buttons are enabled, Display Available Designs and Designs. The other buttons are enabled after you complete the Designs sub-dialog box.

- Click Display Available Designs.

For most design types, Minitab displays all the possible designs and the number of required experimental runs in the Display Available Designs dialog box. Select 3-level L-9 [2-4] Orthogonal Array.

- Click OK to return to the main dialog box.

Under Type of Design, select 3- level type of design. From Number of factors, select 3.

- Click Designs.

Select L9 [3^3] design. Click OK to return to the main dialog box. All the buttons are now enabled.

- Click Factors.

Enter the factor names and set the factor levels. Click OK to return to the main dialog box.

- Randomise and store the design.

By default, Minitab randomises the run order of all design types, except Taguchi designs. Randomization helps to ensure that the model meets certain statistical assumptions. Randomization can also help to reduce the effects of factors that are not included in the study.

Cutting Speed (m/min)	Feed (mm/rev)	Depth of Cut (mm)
1	1	1
1	2	2
1	3	3

Design of

2	1	2
2	2	3
2	3	1
3	1	3
3	2	1
3	3	2

experiments in coded form

Design of experiments in uncoded form

Cutting Speed (m/min)	Feed (mm/rev)	Depth of Cut (mm)
14.5	0.02	0.2
14.5	0.04	0.4
14.5	0.06	0.6
24.9	0.02	0.4
24.9	0.04	0.6
24.9	0.06	0.2
39.2	0.02	0.6
39.2	0.04	0.2
39.2	0.06	0.4

Chapter 4
Experimental Investigation

Chapter 4

Experimental Investigation

4.1 Machine tools

The tests are carried out on a 3 axis CNC Drilling Machine. This machine has a high end 1 KW AC Servo motor is attached for operation in different axes is presented in Figure 1.

Figure 1 Investigational test setup with workpieces and cutting tools

Specifications of the test set up are mentioned below: 3 axis CNC Drilling machine High speed spindle, 3.5 KW spindle, rated at 18000 RPM, Kistler 8793 accelerometer mounted on spindle housing to enable vibration monitoring and PC-based CNC controller SC06 with interface to the accelerometer to enable adaptive control. In house developed adaptive controller package by using Matlab, which runs on standard G/M codes – this will be modified to enable adaptive control algorithm to be run based on the screen shot shown below Figure 2. As part of the present investigation, Al6082 specimens used as workpiece materials in form of plate with dimensions 150mmX100mmX15mm and both coated and uncoated end drill cutters with Ø 6mm, Ø 12mm, Ø 20 mm are used as cutting tools.

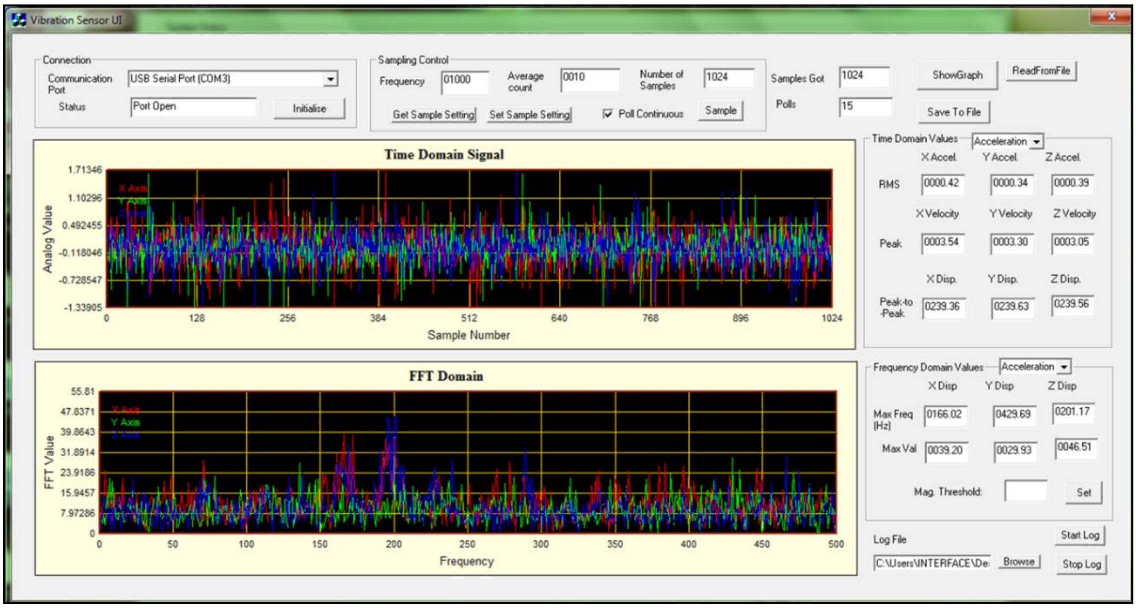


Figure 2 console for vibration signal analysis

4.2 Work piece materials

Most commonly used materials in aircraft and automobile industry such as aluminum alloys (Al6082) of dimensions (150mmX150mm X10mm) are selected as specimens for experimental investigation. Table 1 provides the mechanical properties and chemical composition of workpiece materials. Tungsten carbide cutter of Ø10mm diameter is used as a cutting tool material. Table 2 presents the specifications of the cutter, whereas,Table 3 gives the chemical composition of cutters tools utilized in the present study.

Table 1 Mechanical properties and chemical composition of workpiece material Al6082 alloy

Workpiece (Young's Modulus)		Mechanical properties							
		Density (kg/m^3)		Hardness, BHN	Yield strength (MPa)	Tensile strength (MPa)	Thermal conductivity (W/m-K)		
Al 6082 (72 GPa)		2800		40	503	150	130		
		Chemical composition of workpiece materials (wt. %)							
Al 6082	Al	Ti	Si	Zn	Cu	Cr	Fe	Mg	Mn
	87.1	0.0-0.1	0.7-1.3	0.0-0.2	0.0 – 0.1%	0.18	0.5 max	0.6-1.2	0.4-1.0

4.3 Cutting tool for drilling

Table2 presents the specifications of the cutter, whereas, Table 3 gives the chemical composition of drilling tool utilized in the present study. The cutting tool for the cutting tests is DIN 338 standard drill cutter of 10 mm diameter is selected. High speed steel drill bit with helix angle 30° and lip angle 55° is used in the investigation and it's specifications are presented in the Table2 and chemical composition of cutting tool are given in Table 3. Throughout the experimentation dry machining condition is maintained. Cutting forces are continuously measured with Kistler force dynamometer at machining combinations by keeping constant depth of the hole as 8 mm.

Table 2 Cutting tool specifications

Properties	HSS
Standard	DIN 338
Diameter, mm	10
Material	HSS
Hardness,HV	918
Type	2-flute Twist drill
Length, mm	133
Flute length, mm	87
Number cutting edges	2
Lip length, mm	4.5
Web thickness, mm	2
Margin, mm	1.25
Point angle °	118
Helix angle °	30
Relief angle °	8-12
Lip angle °	55
Coating	Uncoated
Cutting direction	Right

Table 3 Composition of chemicals of drill (wt. %)

HSS	Si	V	Cr	Mn	Ni	Nb	Mo	Co	Fe
	3.709	1.95	3.97	0.046	0.688	0.792	6.46	4.382	77.993

4.4 Data Acquisition System

Data is obtained from Kistler Tri-Shear accelerometer and saved on to disk form the same adaptive controller. Specifically for this Project, The Acquisition system is designed in such a way that for every block in G Code, data is logged for X,Y,Z directions in separate Comma separated files (.csv) (i.e N020.csv, N040.csv, N080.csv, N100.csv etc.). The data obtained is normalized and calibrated from the K-Shear datasheet. We use FFT and HHT for the data analysis which is the most important part in the project. Several plots were generated and data was analyzed.

4.5 Experiment Design

In metal cutting forces and vibration play an important role.In drilling, vibrations arise during the machining process that can be beneficial if they lead to lesser friction and forces. In this chapter, an experimental methodology has been developed for vibration monitoring studies of with stationary workpiece and rotating drilling cutter as cutting tool in end drilling. A methodology has been formulated for identifying and estimating the displacement in the machining system using a Kistler 8793 tri axial accelerometer. FFT analysis of measured signal is performed to quantify the vibration parameter i.e., displacement in the acquired vibration signal. This displacement parameter value is used as a basis for real time tool performance evaluation as part tool condition monitoring in drilling.

An experimental setup is designed, to investigate the effects of vibration intensities on tool wear and tool life and thereby establishing a relation between them. The displacement amplitude, due to vibration at different frequencies, is used in experimental investigation to develop a base for real-time tool condition monitoring during drilling. To improve the sensitivity in non-contact measurements of rotating cutting tools a laser Doppler Vibrometry based method has been introduced.

In the present work, a drilling operation to produce holes of 10 mm diameter with a multi-point DIN 338 standard both high speed steel and uncoated tungsten carbide drill bit cutting tools are critically studied. The test samples of Al-6082 alloy plates, with rectangular cross section with 10 mm thickness, are used in drilling. Experiments in this work help to identify the presence of displacement due to vibration during operations by using a Kistler 8793 tri axial accelerometer. It is used as a feedback device for non-contact vibration measurement so as to predict the required level chatter vibration which can be tolerated. Besides dynamic conditions, machining parameters are also important and influential on tool wear and tool life in metal removing processes in order to define the behavior of wear mechanism under chatter conditions at different cutting conditions; different cutting parameters are also applied in the tests. The cutting parameters, in a standard machining process, are cutting speed (V), feed rate(f) and depth of cut (b).The depth of cut value varies in every chatter condition and tool holder length. The depth of cut value is kept at8 mm as constant. The depth of cut values are for stable condition(S), chatter condition(C) and the severe chatter condition (SC), respectively. Entire experiment is divided into two parts, hence, the setup is modified to suit the requirements of face turning on two different materials. Experiments were carried out according to optimized test conditions as per Taguchi Orthogonal array (L9) for drilling operation. According to the Taguchi method, if three parameters and 3 levels for each parameters L9 orthogonal array should be employed for the experimentation. These vibration causes low or high-frequency displacements in feed direction which leads to defects in the hole diameters, accelerated wear, and decreases tool life. The purpose of experiments is to evaluate the drill bit performance based on vibration levels and establish a relationship with tool life at different drilling conditions as listed in Table4.

Table4 Factors and levels used in the experiment

Levels	Factors		
	1	2	3
Spindle speed, N (RPM)	465	795	1250
Feed rate, f (mm/min)	80	120	160
Depth of cut(mm)	0.2	0.4	0.6
Workpiece hardness, H(Vickers)	Al 6082 (40 BHN)		
Drill tool materials	High speed steel		

4.6 Vibration

One of the significant issues upsetting the performance of the machine tool utilized for a drilling operation is spindle vibrations. Vibrations in spindle openly deflect the end quality of the parts machined. In drilling, the spindle vibrations can have profound effects on the performance of the drill bit because it can introduce roundness error, and waviness in drilled holes. It is, therefore, necessary to achieve those cutting speeds without chatter and bearing failure. The spindle, as it vibrates, under the action of different machine elements such as gears, belt drives and the drill bit which is in interaction with the workpiece, which in turn is mounted at the nose of the spindle, can introduce substantial variations in vibration levels and this is the main focus in this section.

4.7 Need of vibration analysis during drilling operation

Machining chatter is a common phenomenon in metal cutting, and drilling is not an exception. The vibration assisted analysis of drilling is the best solution to predict this complex phenomenon. Due to vibrations produced by the drill, accuracy of the drilled holes gets affected. With increased surface finish, problems in assembly arise, which results in inappropriate machining problems with unsuitable assembled machinery parts. Therefore, vibration levels, during drilling operation, must be quantified and monitored to produce drilled holes with required quality.

4.8 Procedural steps

- The drilling operation is performed using a 2-flute drill bit.
- The workpiece is fixed firmly on the work table.
- Kistler 8793 tri axial accelerometer is mounted on the spindle axis
- Perform FFT analysis for vibration signal to quantify the vibration parameter i.e., displacement in microns.
- Every test is initiated with a new drill bit and vibration data acquired while drilling and machining is stopped after drilling the 5thcut in every test condition for tool wear measurement.
- In all test conditions, the same procedure has been adopted to acquire data.
- Inspect the drilled holes for roundness measurement under coordinate measuring machine.

The above listed steps have been executed to carry out experiments on real time test set up presented in Figure1as part of the investigation with Kistler 8793 tri axial accelerometer.

4.9 Tool Rejection Criteria Adopted In the Present Study

In the present work, the performance of the drill bit is evaluated based on both ISO 10816-3 and ISO 3685. According to ISO 3685 standard, three conditions of the tool are considered: sharp tool (flank wear VB= 0 mm), the semi-dull tool (Flank wear VB≤ 0.3mm), and dull tool (flank wear VB ≥0.3 mm) in drilling [159]. Tool wear (VB) is estimated by using the following relation eq. 1 by direct method as shown in Figure 3. Where ‘α’ is the rake angle of the cutter (in degrees), ‘γ’ is the relief angle of the drill bit (in degrees) and ‘ΔD’ is the change in the diameter of the drilling cutter (mm) due to tool wear.

$$VB = [\{1 / \tan(\gamma)\} - \tan(\alpha)] * [\Delta D/2] \text{ mm} \qquad (3.1)$$

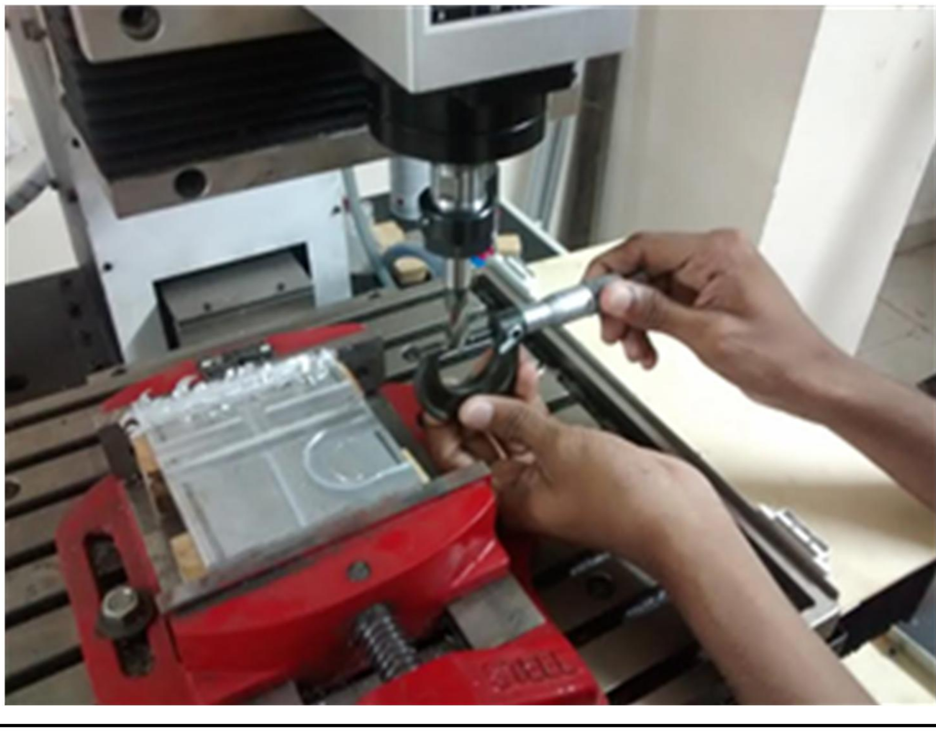


Figure 3Tool wear measurement by using direct method.

As per ISO 10816, displacement value for a rotating object (drill bit) up to 20 microns do not have any effect on drill bit flank wear. Tool flank wear is found to be affected by displacement values between 20 microns and 60 microns. Any value of displacement parameter beyond 60 microns is not acceptable as per standard.

Chapter 5
Experimental Results

Chapter 5

Experimental Results

5.1 EXPERIMENTAL OBSERVATIONS

5.1.1 Acquisition And Analysis Of Vibration Signal In The Experiment

In this study, there are three stages of tool is considered namely sharp tool, dull tool and semi dull tool. A direct contact method have been used, both the actuation and the data acquisition are performed using a Kistler_8793A triaxial accelerometer coupled with pre amplifier and on board FFT analyzer and a desktop PC running an in house developed programming model as an adaptive controller for CNC drilling. Figure 4 gives in house developed console for vibration acquisition and signal analysis.

5.1.2 Signal Processing

The actual implantation of an on line adaptive control monitoring system typically starts with designing a proof-of-concept experiment. First, an excitation mechanism for vibration testing is determined. Then, the physical quantities are measured; the type and number of sensors, and the sensor placement are decided. Next, the issue of data acquisition is addressed, such as how often the data should be collected, how to select the resolution and dynamic ranges of the measured quantities, which antialiasing filter should be applied, and so on. Finally, the recorded data should be transmitted safely to central monitoring facilities or to interested users of the data. The selection of data acquisition and signal-processing strategies is application specific, and economic considerations play a major role in these decisions. A proper selection and design of data acquisition systems and signal processing procedures should be eventually based on *a prior* numerical simulation of the test systems.

Piezo smart triaxial accelerometer based tool wear identification is essentially subject to interpretation of the captured signals. However, the extraction of key features useful for tool wear identification from the collected accelerometer signal usually involves a number of confounding problems, such as contamination from diverse noise, interference from natural structural vibration, confusion of multiple modes and bulkiness of sampled data. Accordingly, various signal processing and identification techniques have been introduced, in particular time-series analysis, frequency analysis and integrated time– frequency analysis. The vibration raw signals are gathered in time domain called waveform graph is shown in figure 5 and converted to frequency domain by FFT analyzer is called spectrum graph as shown in figure 6. The spectrum graph provides more information about machining process than the waveform graph. The vibration parameter used to analyze the vibration signal in frequency domain is displacement.

5.1.3 Time Domain Analysis

The direct time domain analysis of a signal can identify tool wear both globally and locally by measuring the displacement amplitude in the acquired acousto optic signal.

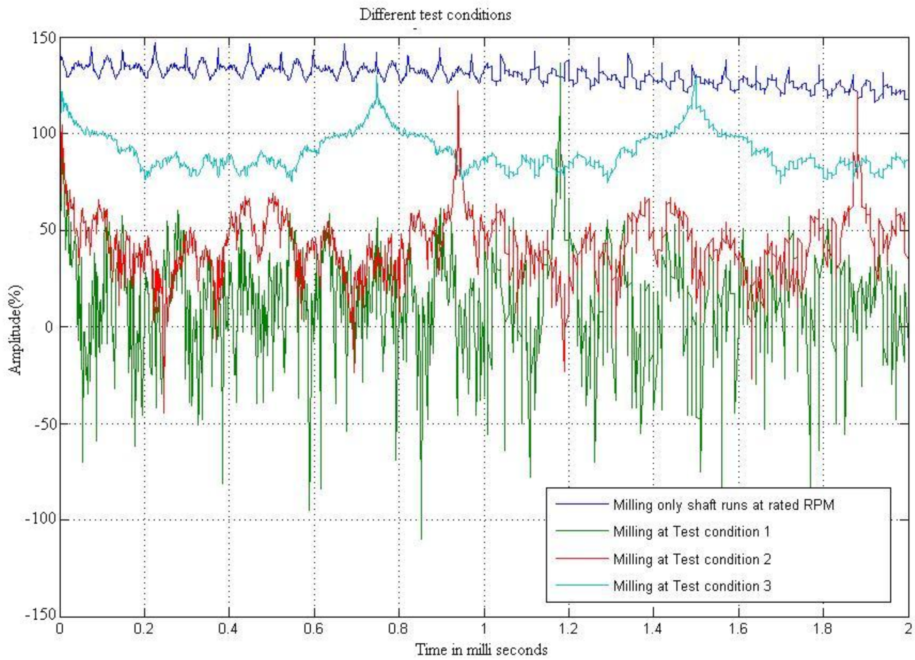


Figure 4 Direct time domain analysis of a signal

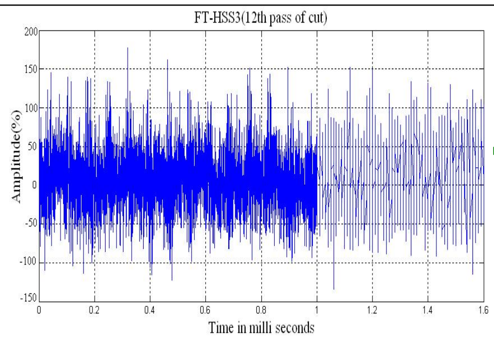
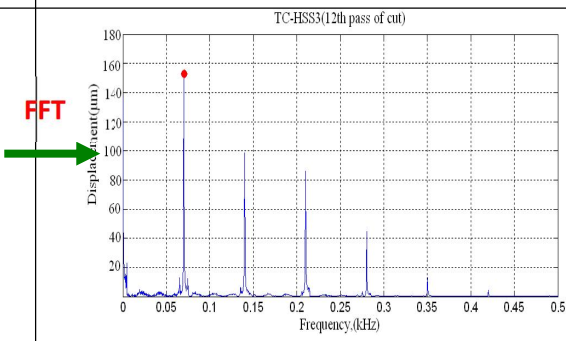
Figure 4 shows a time-series analysis, applied to the wave signals for detecting amplitude of displacement with the aid of a two-stage prediction model, to find that the difference in the signals in the time domain between with cutting condition and without cutting (only spindle runs at rated speed), defined as residual error, would be maximized for the sensors near the damage. All the time domain signals in the present work are filtered using a 0-500Hz band pass filter and signal processing involves signal blocks of 4000 data points collected over a sampling interval 500 drilli seconds.

For illustration purpose a time domain signal output for displacement amplitude is presented in figure 5 and this figure also shows the difference in amplitude with and without cutting conditions.

5.1.4 Frequency Domain Analysis

Direct time-series analysis is normally incapable of isolating defect-scattered information appropriately from noise in different frequency bands. Additionally, a benchmark signal is essential for comparison. It is more usual to examine a dynamic signal in the frequency domain via Fourier transform (FT). Originating from FT but with enhanced ability, fast Fourier transform (FFT) and its 2D form (2D-FFT) are able to speed up this transform, and are widely used for acousto optic emission wave signal analysis.

Figure 5 shows the response of dynamic signal in the frequency domain by applying 2D-FFT to direct time signal in time domain. A comparative spectrum is shown in figure 6 among different combinations in the experiment. In figure 6, test condition 3 of end drilling is presented which exhibits correlation between displacement and condition of the tool. The detailed results and discussion are presented in the next chapters. The spectrum graph provides more information about machining process than the waveform graph. Experimental findings associated with spectrum graphs will

EM-HSS-3-Time	**EM-HSS-3-FFT**
	

be discussed in detail in the next chapter for different machining and test conditions.

Figure 5 Response of dynamic signal in frequency domain

The change in phase of vibration signal varies according to progression in flank wear value. This phase shift occurs when flank wear crosses its rejection value ($VB \geq 0.3mm$) and it is presented in figure 6. From the figure 6 it is observed that the spectral energy in a certain frequency band is sensitive to displacement it can be a most effective features that can be used in a monitoring system. The worn tool causes the machining process to change from smooth cutting to an irregular breakaway process, which causes the normal vibration amplitudes to increase. This is especially true for normal flank: wear situations, which will cause the vibration amplitudes over a wide frequency range to increase. The spectral energy in the frequency band 0-8000Hz is sensitive to tool wear due to the loss of material at the tool tip.

In the present work, a criterion such as ISO 10816-3, is used for decision making based on vibration parameter values i.e., displacement values for monitoring the drill bit performance and its evaluation. In all test conditions for different variations, displacement value of target vibrating object are easily perceived by analyzing the acousto optic emission signal at different stages of tool wear.

5.1.5 Correlation between tool wear and displacement

The spectral energy in a certain frequency band is one of the most compelling features that can be used in a monitoring system. The worn tool causes the machining process to change from smooth cutting to an irregular breakaway process, which causes the typical vibration amplitudes to increase as anticipated according to literature. Every test combination is initiated with a new tool to avoid any influence of wear and continued up to 20 holes.The relationship between vibration amplitude and flank wear can be explained as follows. It is known the fact that the friction between the tool and the workpiece is little when the tool is new, and accordingly, the amplitude of vibration will also be small. Further increase in vibration amplitude is because of the increasing friction between the workpiece and a cutting tool which is due to increase in tool wear.

After that, a peak appears as the tool reaches and passes its wear limits, after which the friction decreases and vibration amplitude drops as the tool fails. The vibration is measured in the feed direction since this direction has more dominant signals than other two directions. The peak amplitude varies from 5 µm to 150 µm depending on the severity of the chatter and cutting speed.

As per ISO 10816-3 for vibration severity standards, displacements, in rotating object up to 20µm,do not have any effect on tool flank wear. Tool flank wear is found to be affected by the measured displacements in the range between 20µm and 60µm. A displacement value beyond 60µm is not acceptable. The results, presented in Tables justify this standard. Any displacement beyond 60µm value is showing excessive vibration which is deteriorating the work-piece surface and reducing the tool life. When the cutting tool is sharp, lower frequency of vibration is mainly excited. As tool wear progresses the cutting force increases hence displacement increases which result in the generation of different frequencies of vibrations of the tool holder and machines structure, resulting in higher components becoming dominant in the signal. Experimental results clearly identify the correlation between tool wear and vibration amplitude. The amplitudes of the peaks become much greater with increasing tool wear leading to the vibration to increase excessively between the tool tip and the workpiece and therefore causes the larger amplitudes at the natural frequency. The dominant failure mode, in this case, is flank wear, which causes vibration amplitudes to increase. Results of the experimental findings of both cutting forces and vibration displacement values at different levels of process parameters are tabulated and presented in Table 5 and Table 6.

Table5 Experimental data while high speed steel (HSS) on Al6082 as per FF, is as follows:

Test condition	Drilling Parameters		Cutting force in feed direction (N)	Displacement in feed direction (µm)	Flank wear, VB (mm)	Tool life (min)
	Vc m/min	f mm/rev				
Al-6082 as work piece material						
E-HSS-1	14.5	0.02	377	5.3	0.05	4.51
E-HSS-2	14.5	0.04	433	12.2	0.10	3.81
E-HSS-3	14.5	0.06	510	27.5	0.15	3.08
E-HSS-4	24.9	0.02	182	10.4	0.12	1.67
E-HSS-5	24.9	0.04	212	21.3	0.19	1.59
E-HSS-6	24.9	0.06	241	46.1	0.26	1.34
E-HSS-7	39.2	0.02	118	31.6	0.18	2.30
E-HSS-8	39.2	0.04	138	52.7	0.26	1.63
E-HSS-9	39.2	0.06	73	64.1	0.31	1.35

To investigate the effect of displacement due to vibration on tool wear, an experimental approach is presented. From the outcomes, it originates that the vibration amplitudes in feed direction increase with increasing the feed rate as expected. A good degree of agreement is identified between tool wear and vibration amplitudes in all conditions. In particular, vibration parameter displacement and cutting force values exhibited similar trend with the progression tool wear of the drill bit throughout the experiment. The effects of change of cutting speed and feed rate at a constant depth of cut are studied which defines the onset of instability. While drilling the Ti-6Al-4V specimen, both drill cutter have completed their effective tool life before drilling the 20th hole, i.e., flank wear (VB) values are found to be more than 0.3mm. Throughout the investigation, the lowest displacement value is measured as 5.3 μm while drilling 5^{th} hole with carbide drill bit in the Al6082workpiece and the highest displacement value is 85.5 μm while drilling holes on Ti-6Al-4V specimen with HSS drill bit. The increase, in the feed rate, causes the growth of the resistance force in the cutting feed direction in entire experimentation. Increase in the feed rate is identified as the cause for the excited vibration appearance associated with a more discontinuous chip. Discoveries of the current work show that the analysis of vibration and cutting force signals can be used to assess the condition of the drill bit (tool wear) in vibration-assisted drilling.

Chapter 6

Results and Discussions

Chapter 6

Results and Discussion

6.1 Grey Relational Analysis

In Grey relational analysis the first step is to perform the Grey relational generation in which the results of the experiments are normalized in the range between 0 and 1 due to different measurement units. Data pre-processing converts the original sequences to a set of comparable sequences. Normalizing the experimental data for each quality characteristic is done according to the type of performance response. Thus, the normalized data processing for corresponding to smaller-the-better criterion can be expressed as:

$$x_i(k) = \frac{y_i(k) - \min y_i(k)}{\max y_i(k) - \min y_i(k)}, \tag{2}$$

The normalized data processing for corresponding to larger-the-better criterion can be expressed as:

$$x_i(k) = \frac{y_i(k) - \min y_i(k)}{\max y_i(k) - \min y_i(k)}, \tag{3}$$

where, i = 1, 2, 3, ..., m, m is the number of experimental runs in Taguchi orthogonal array, in the present work L9 orthogonal array is selected then m = 9. k = 1, 2, ...,n, n is the number of quality characteristics or process responses, Min yi (k) is the smallest value of yi (k) for the k th response. Max yi (k) is the largest value of yi (k) for the k th response. xi (k) is the value after Grey relational generation. The normalized values of surface roughness and material removal rate calculated by Eq. (2) and (3) are shown

Table 6.1 Deviation sequence values using GRA

sl no	C.F	DISP	V.B	T.L
1	0.695652174	0	0	0
2	0.823798627	0.117346939	0.192307692	0.220820189
3	1	0.37755102	0.384615385	0.451104101
4	0.249427918	0.086734694	0.269230769	0.895899054
5	0.318077803	0.272108844	0.538461538	0.921135647
6	0.384439359	0.693877551	0.807692308	1
7	0.102974828	0.447278912	0.5	0.697160883
8	0.148741419	0.806122449	0.807692308	0.90851735
9	0	1	1	0.996845426

Table 6.2 Normalized values using GRA

sl no	C.F	DISP	VB	T.L
1	0.304347826	1	1	1
2	0.176201373	0.882653061	0.807692308	0.779179811
3	0	0.62244898	0.615384615	0.548895899
4	0.750572082	0.913265306	0.730769231	0.104100946
5	0.681922197	0.727891156	0.461538462	0.078864353
6	0.615560641	0.306122449	0.192307692	0
7	0.897025172	0.552721088	0.5	0.302839117
8	0.851258581	0.193877551	0.192307692	0.09148265
9	1	0	0	0.003154574

6.2 Grey relational coefficient and Grey relational grade

The second step is to calculate the Grey relational coefficient based on the normalized experimental data to represent the correlation between the desired and actual experimental data. The overall Grey relational grade is then computed by averaging the Grey relational coefficient corresponding to each performance characteristic. As a result, optimal combination of process parameters is evaluated considering the highest Grey relational grade by using the Taguchi method. Based on the normalized experimental data the Grey relation coefficient can be calculated using the following equations:

$$\xi_i(k) = \frac{\Delta_{\min} + \varsigma\Delta_{\max}}{\Delta_{0i}(k) + \varsigma\Delta_{\max}},$$

$$\Delta_{0i}(k) = \left\| x_0(k) - x_i(k) \right\|,$$

$$\Delta_{\max} = \max_{\forall j \in i} \max_{\forall k} \left\| x_0(k) - x_i(k) \right\|,$$

$$\Delta_{\min} = \min_{\forall j \in i} \min_{\forall k} \left\| x_0(k) - x_i(k) \right\|,$$

Table 6.3 Grey relational coefficient and grade

GREY RELATION CO-EFFICIENT				
C.F	DISP	V.B	T.L	grade
0.418181818	1	1	1	0.854545455
0.377700951	0.809917355	0.722222222	0.693654267	0.650873699
0.333333333	0.569767442	0.565217391	0.525704809	0.498505744
0.667175573	0.852173913	0.65	0.35819209	0.631885394
0.611188811	0.647577093	0.481481481	0.351831299	0.523019671
0.565329884	0.418803419	0.382352941	0.333333333	0.424954894
0.829222011	0.527827648	0.5	0.417654809	0.568676117
0.770723104	0.3828125	0.382352941	0.354983203	0.472717937
1	0.333333333	0.333333333	0.334035827	0.500175623

RESPONSE TABLE FOR MEAN GREY RELATIONAL GRADE				
PARAMETERS	GREY RELATIONAL GRADE			
	LEVEL-1	LEVEL-2	LEVEL-3	DELTA
C.S (A)	0.667974	0.526619	0.513856	0.154118
F (B)	0.685035	0.54887	0.474545	0.21049
DOC (C)	0.584072	0.594311	0.5300671	0.0540049

where $\Delta oi= ||x0(k) - xi(k)||$ is difference of the absolute value between x0(k) and xi(k), x0(k) is the reference sequence of the k th quality characteristics. Δmin and Δmax are respectively the minimum and maximum values of the absolute differences (Δoi) of all comparing sequences. ζ is a distinguishing coefficient, $0 \leq \zeta \leq 1$, the purpose of which is to weaken the effect of Δmax when it gets too big and thus enlarges the difference significance of the relational coefficient. In the present case, ζ = 0,5 is used due to the moderate distinguishing effects and good stability of outcomes. The Grey relation coefficient of each performance characteristic is shown. After averaging the Grey relational coefficients, the Grey relational grade γi can be calculated as follows

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n}\xi_i(k), \quad (8)$$

where, i = 1, 2, 3 ... 9, (L9 orthogonal array is selected), ξi(k) is the Grey relational coefficient of k th response in i th experiment and n is the number of responses. The optimum level of the process parameters is the level with the highest Grey relational grade. The higher value of the Grey relational grade corresponds to an intense relational degree between the reference sequence x0(k) and the given sequence xi(k). The Grey relational coefficients and Grey relational grade are presented calculated by Eq. (4) and (8), respectively. The highest Grey relational grade is the rank of 1.

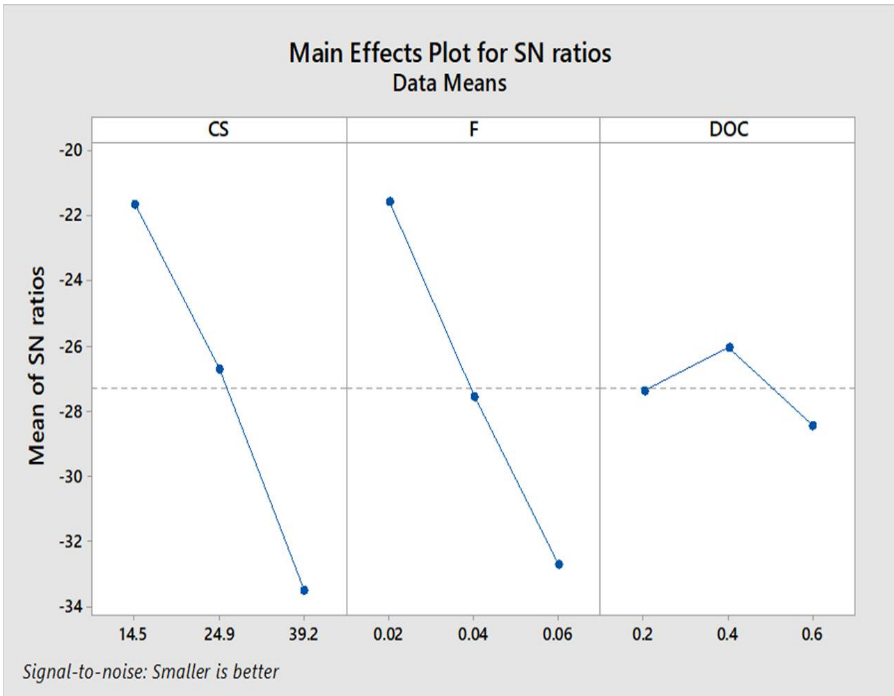
The multi-objective optimization problem has been transformed into a single equivalent objective function optimization problem using Grey relational analysis. Accordingly, optimal combination of process parameters is evaluated considering the highest Grey relational grade by using the Taguchi method.

6.3 Analysis of S/N ratios

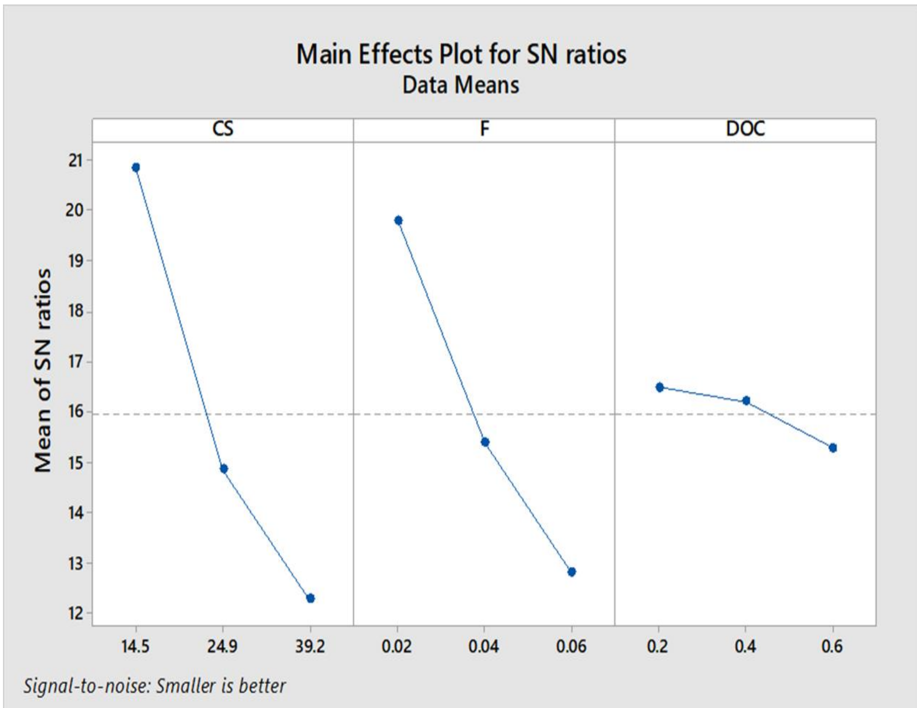
Taguchi method recommends the use of the S/N ratio to measure the quality characteristics deviating from the desired values [19]. The signal-to-noise (S/N) ratio is a measure of the magnitude of a data set relative to the standard deviation. In the Taguchi method, signal to-noise S/N ratio is used to represent a performance characteristic and the largest value of S/N ratio means the optimal level of the turning parameters. There are three types of S/N ratio: the larger-the better, the nominal-the better, and the smaller-the-better. S/N ratio based on the larger-the-better criterion for the overall Grey relational grade calculated using

$$S/N = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right], \quad (9)$$

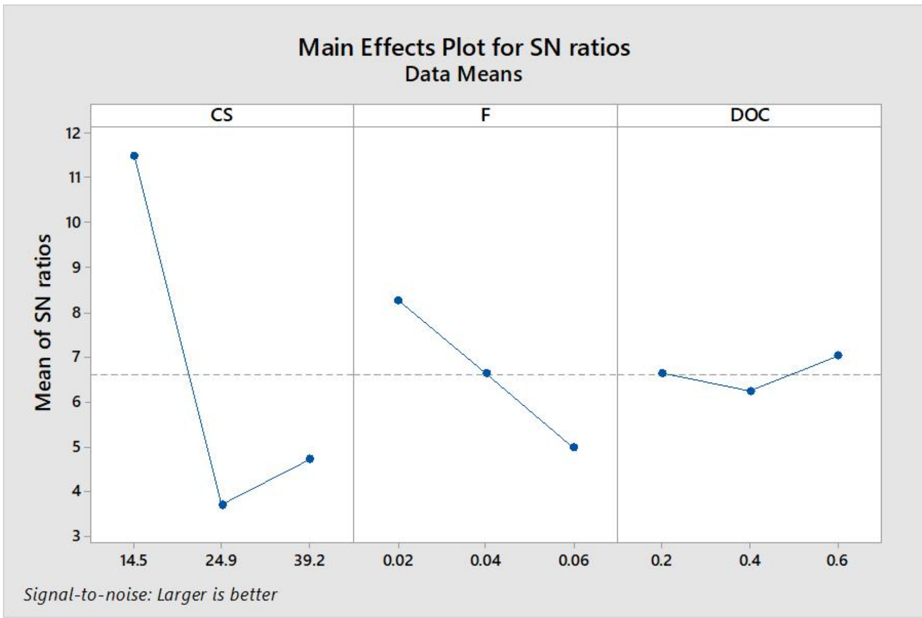
Cutting Force



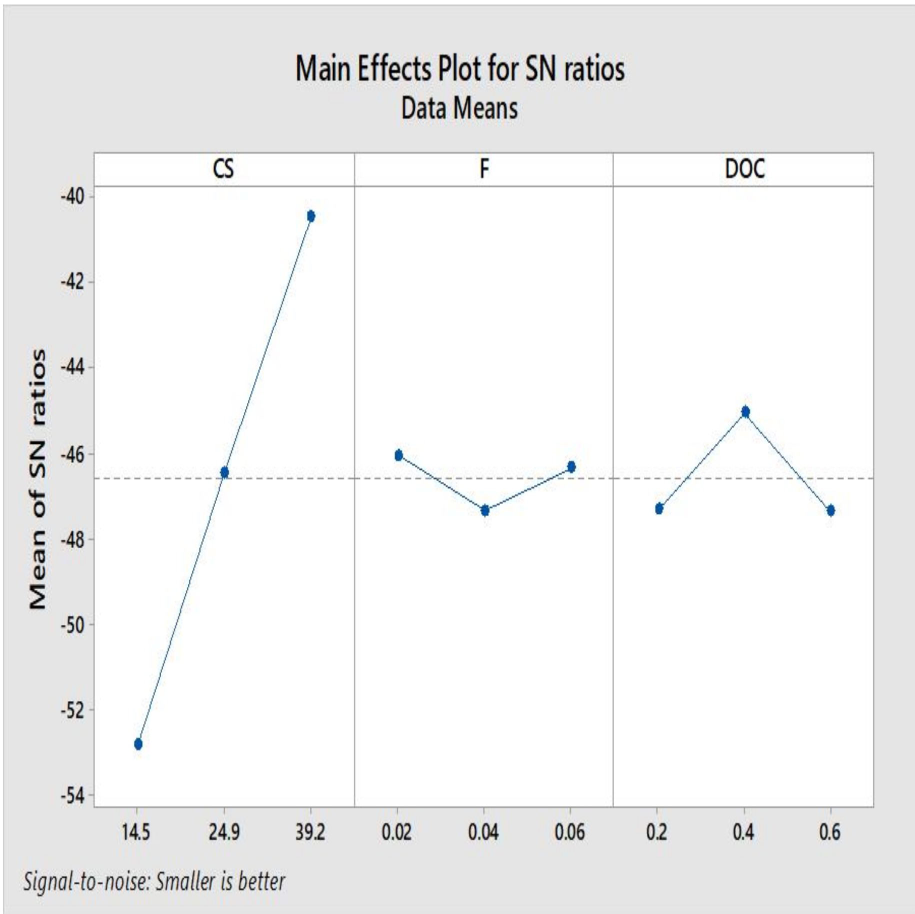
Displacement



Tool Life



Flank Wear



where n is the number of measurements, and yi is the measured characteristic value. The Mean response for the Grey relational grade with its grand mean and the main effect plot of the Grey relational grade are very important because the optimal process condition can be evaluated from this plot, (shown in Fig. 1. and 2.). The dashed line is the value of the total mean of the S/N ratio and mean effect plot.

The means of the Grey relational grade for each level of drilling parameters were calculated and summarized . The larger the Grey relational grade, the better the multiple quality characteristics.

As the optimal parameter condition for drilling of the AL6082 regarding tool life ,flank wear and cutting force multiple performance characteristics are levels: A-level 1, B-level 1, C-level 2. Namely, cutting speed of V = 14.5 m/min, feed rate of f = 0.02 mm/rev and depth of cut d = 0.4 mm

6.4 ANOVA (Analysis Of Variance)

The purpose of the analysis of the variance (ANOVA) is to investigate which drilling parameters significantly affect the quality characteristic. By using the Grey relational grade value, ANOVA is indicated for identifying the significant factors. In addition to degree of freedom (DF), mean of squares (MS), sum of squares (SS), F-ratio and contribution (C) associated with each factor was presented. The higher the percentage contribution was, the more important the factor was for affecting the performance characteristics

Table Anova for contribution of parameters on cutting force

Main control factors	Symbol	Degree of freedom DF	Sum of squares SS	Mean of squares MS	F-Ratio	Contribution C(%)
Cutting speed V	A	2	171660.2222	85830.11111	32.99325161	93.02284414
Feed f	B	2	3836.222222	1918.111111	0.737325418	2.078852615
Depth of cut d	C	2	3836.222222	1918.111111	0.737325418	2.078852615
Error	-	2	5202.888889	2601.444444	1	2.819450633
Total	-	8				100

The results ANOVA indicates that the percentage contribution of individual process parameters of drilling process for 'cutting force'. The percentage contribution of cutting speed, N is 93.023 %, Feed rate, f is 2.0789 %, Depth of cut is 2.0789 % and error is of 2.81 % . The error obtained is due to machine vibration during high speed drilling.

Table Anova for contribution of parameters on displacement

Main control factors	Symbol	Degree of freedom DF	Sum of squares SS	Mean of squares MS	F-Ratio	Contribution C(%)
Cutting speed V	A	2	1910.856667	955.4283333	-1.447827086	57.33590579
Feed f	B	2	1370.846667	685.4233333	-1.038669708	41.13272162
Depth of cut d	C	2	1370.846667	685.4233333	-1.038669708	41.13272162
Error	-	2	-1319.81	-659.905	1	-39.60134904
Total	-	8				100

The percentage contribution of individual process parameters of drilling process for 'Displacement'. The percentage contribution of cutting speed, N is 57.336 %, Feed rate, f is 41.133 %, Depth of cut is 41.133 % and error is of 39.601 %

Table Anova for contribution of parameters on flank wear

Main control factors	Symbol	Degree of freedom DF	Sum of squares SS	Mean of squares MS	F-Ratio	Contribution C(%)
Cutting speed V	A	2	0.0342	0.0171	-	59.375

					1.531343284	
Feed f	B	2	0.022866667	0.011433333	- 1.023880597	39.6990741
Depth of cut d	C	2	0.022866667	0.011433333	- 1.023880597	39.6990741
Error	-	2	- 0.022333333	- 0.011166667	1	-38.773
Total	-	8				100

The percentage contribution of individual process parameters of drilling process for 'FLANK WEAR'. The percentage contribution of cutting speed, N is 59.375 %, Feed rate, f is 39.699%, Depth of cut is 39.699 % and error is of 38.773 %.

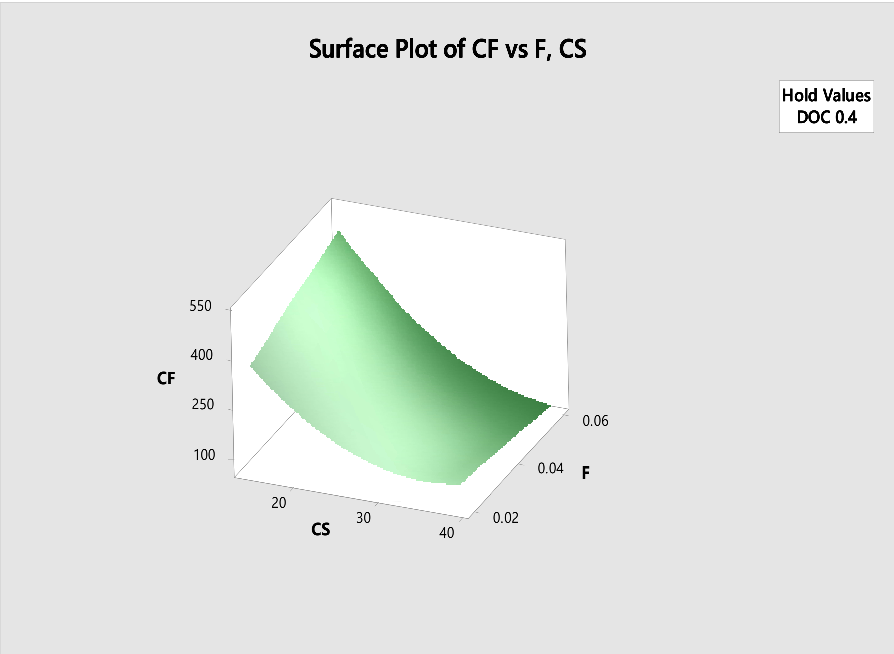
Table Anova for contribution of parameters on tool life

Main control factors	Symbol	Degree of freedom DF	Sum of squares SS	Mean of squares MS	F-Ratio	Contribution C(%)
Cutting speed V	A	2	9.350755556	4.675377778	- 10.46440029	85.71422751

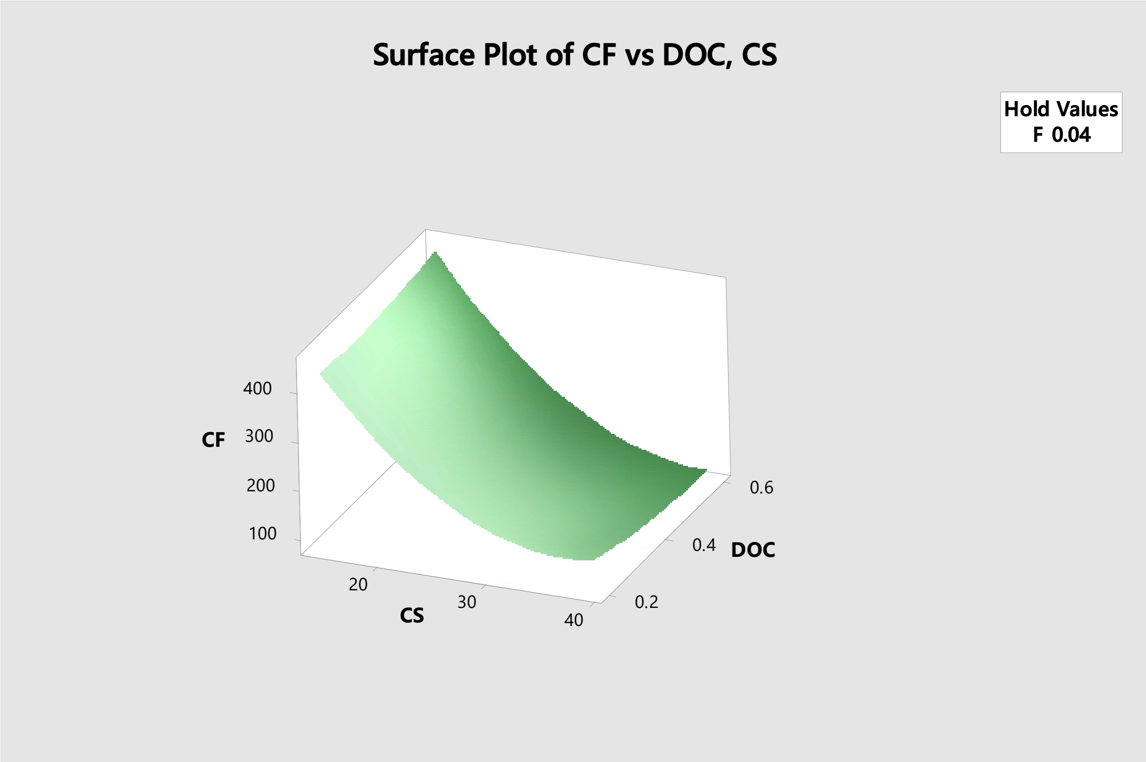
Feed f	B	2	1.226022222	0.613011111	-1.372037502	11.23840176
Depth of cut d	C	2	1.226022222	0.613011111	-1.372037502	11.23840176
Error	-	2	-0.893577778	-0.446788889	1	-8.191031034
Total	-	8				100

The percentage contribution of individual process parameters of drilling process for 'TOOL LIFE'. The percentage contribution of cutting speed, N is 85.714 %, Feed rate, f is 11.238%, Depth of cut is 11.238% and error is of 8.191 %. The error obtained is due to machine vibration during high speed drilling.

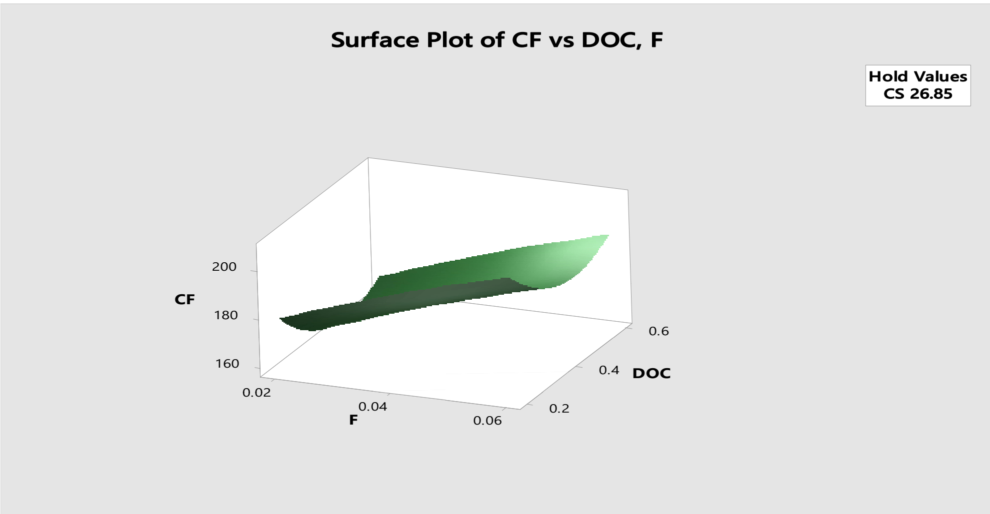
6.5 Surface Plots



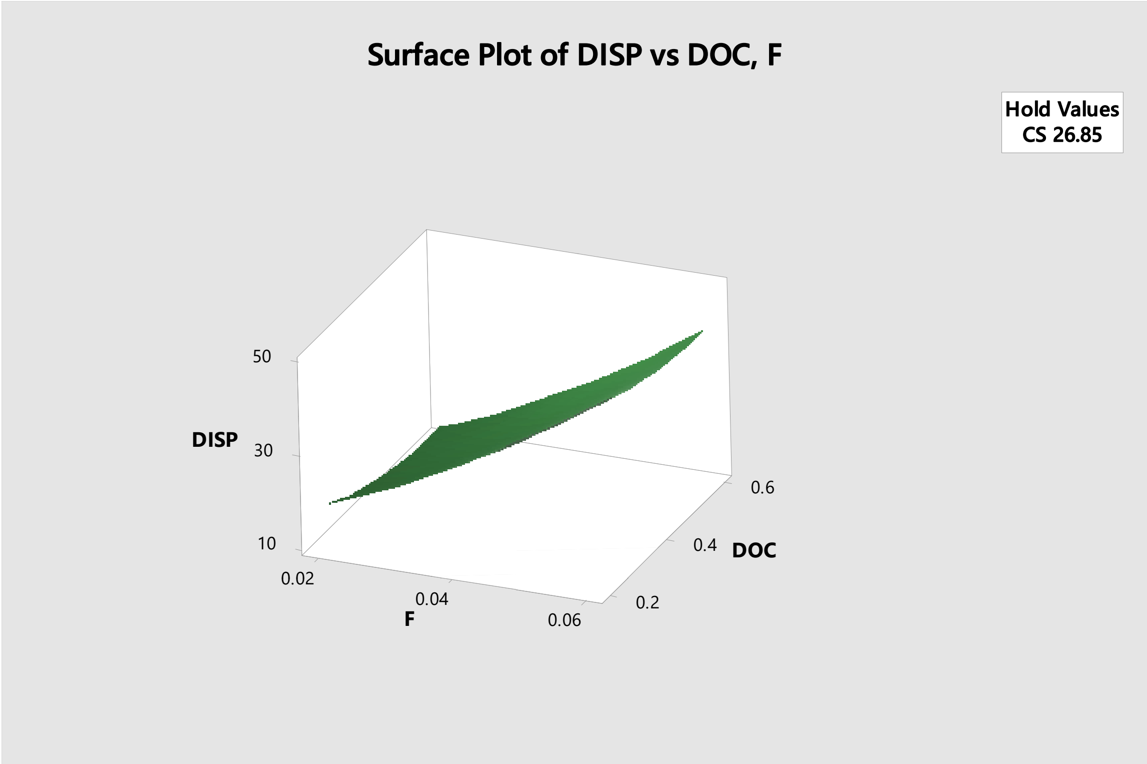
The surface plot of cutting force vs cutting speed and feed gives relationship between cutting force ,cutting speed and feed. From the graph the cutting force is minimum when the cutting speed is maximum and the feed is also maximum.



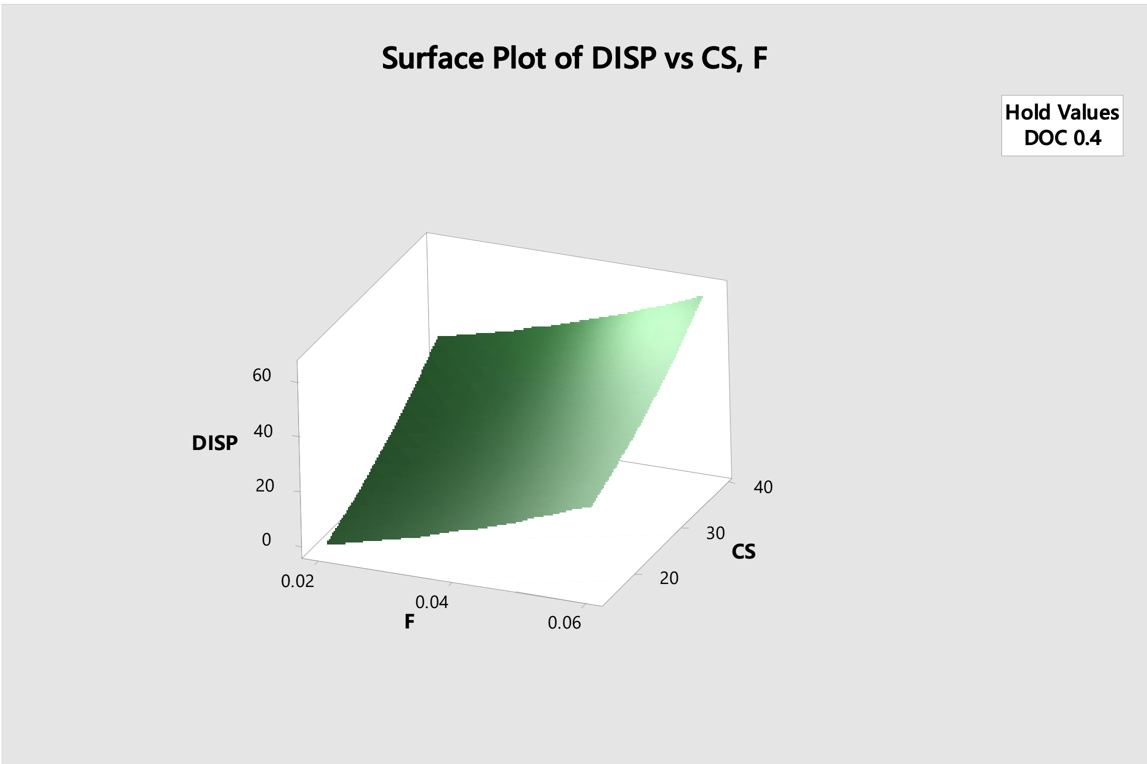
The surface plot of cutting force vs depth of cut and cutting speed gives relationship between cutting force ,depth of cut and cutting speed. From the graph the cutting force is minimum when the depth of cut is maximum and the cutting speed also maximum.



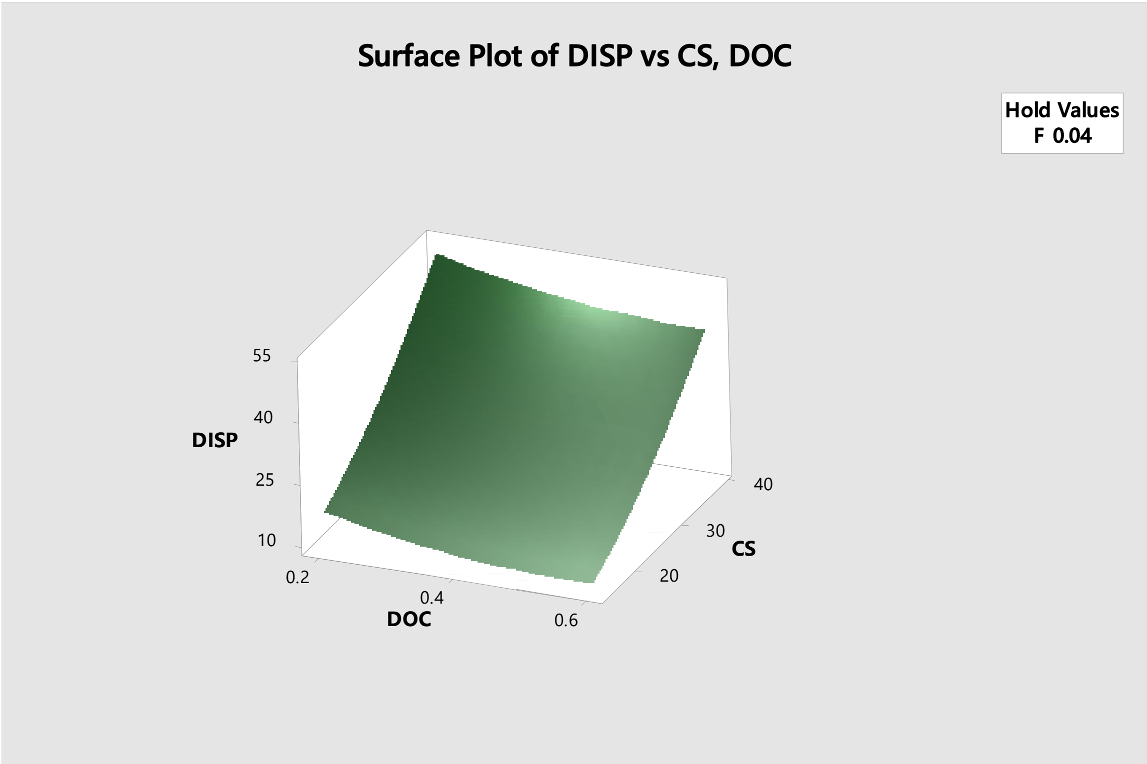
The surface plot of cutting force vs depth of cut and feed gives relationship between cutting force ,depth of cut and feed. From the graph the cutting force is minimum when the depth of cut is maximum and the feed is minimum.



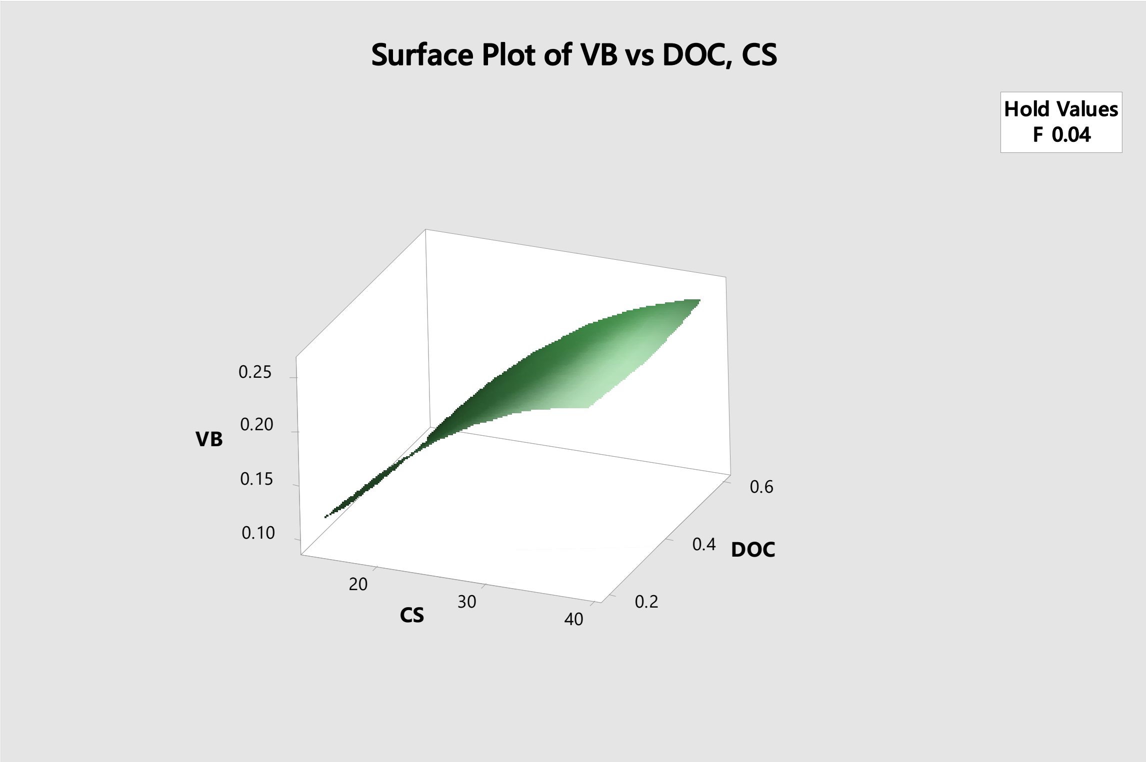
The surface plot of displacement vs feed and depth of cut gives relationship between displacement feed and depth of cut.From the graph it can be observed that displacement is minimum when feed is minimum and depth of cut is
maximum



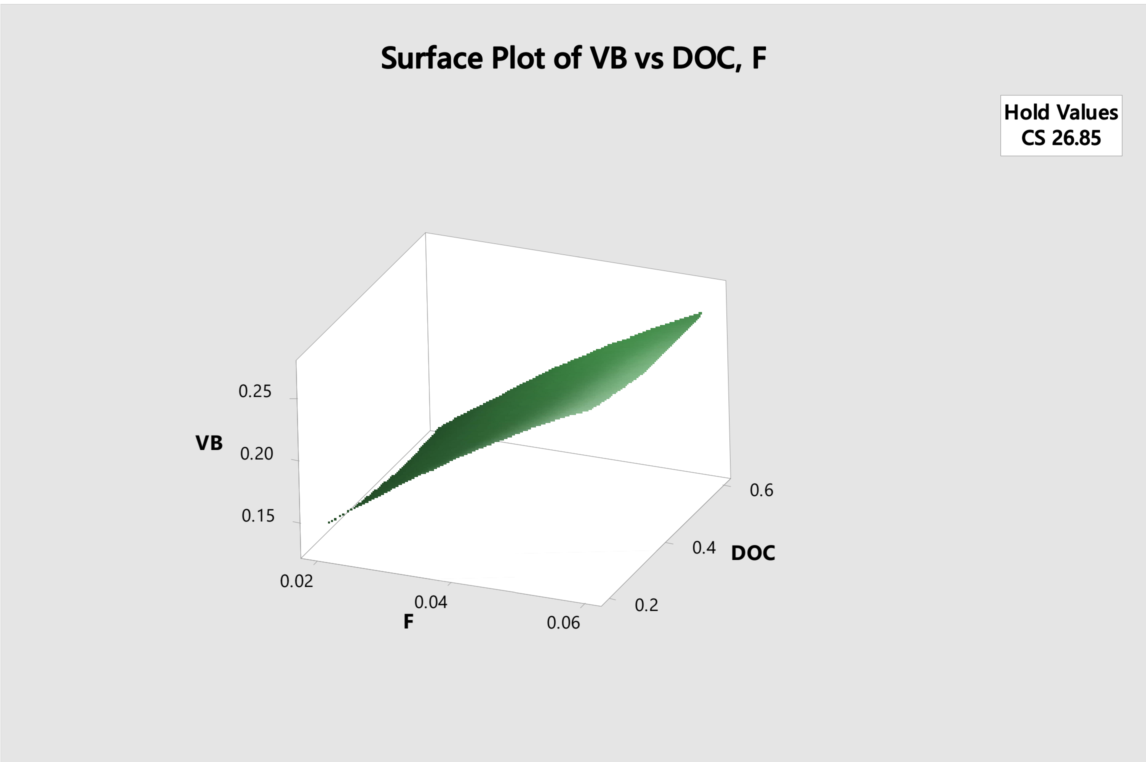
The surface plot of displacement vs cutting speed and feed gives relationship between displacement cutting speed and feed.From the graph it can be observed that displacement is minimum when cutting speed and feed are minimum.



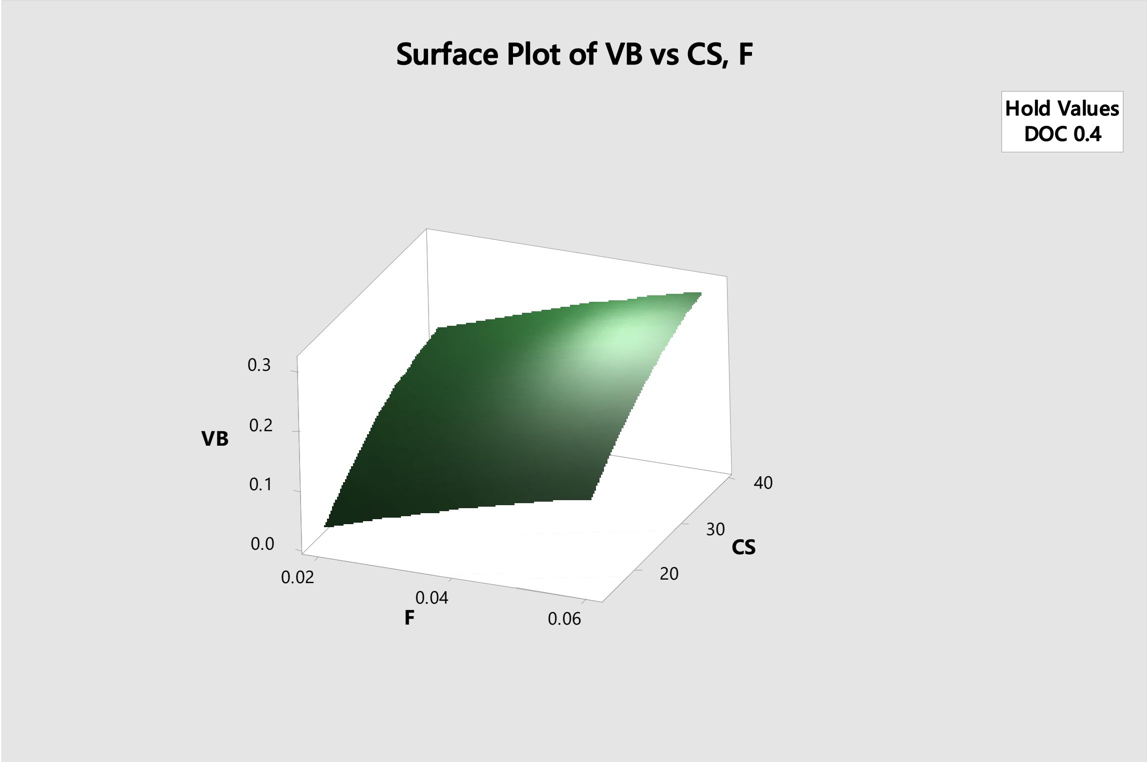
The surface plot of displacement vs cutting speed and depth of cut gives relationship between displacement cutting speed andfeed.From the graph it can be observed that displacement is minimum when cutting speed is low and depth of cut is maximum



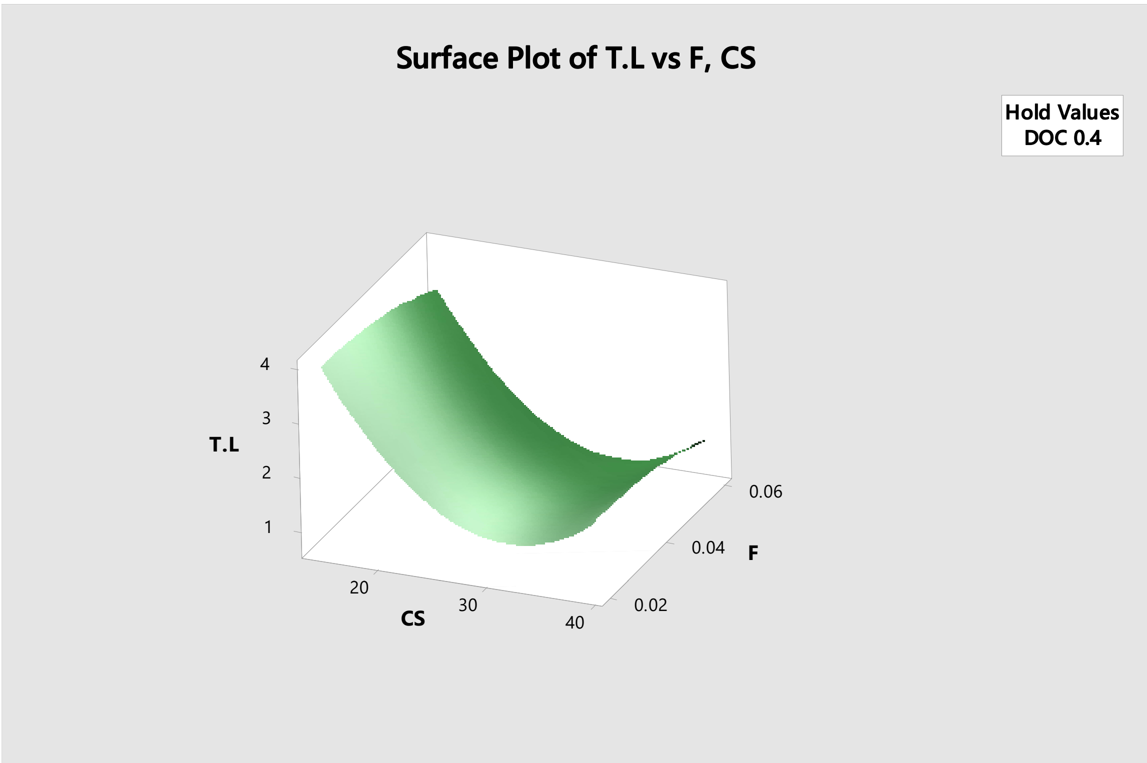
The surface plot of flank wear vs cutting speed and depth of cut gives relationship between flank wear cutting speed and depth of cut.From the graph it can be observed that flank wear is minimum when cutting speed is minimum and depth of cut is
maximum



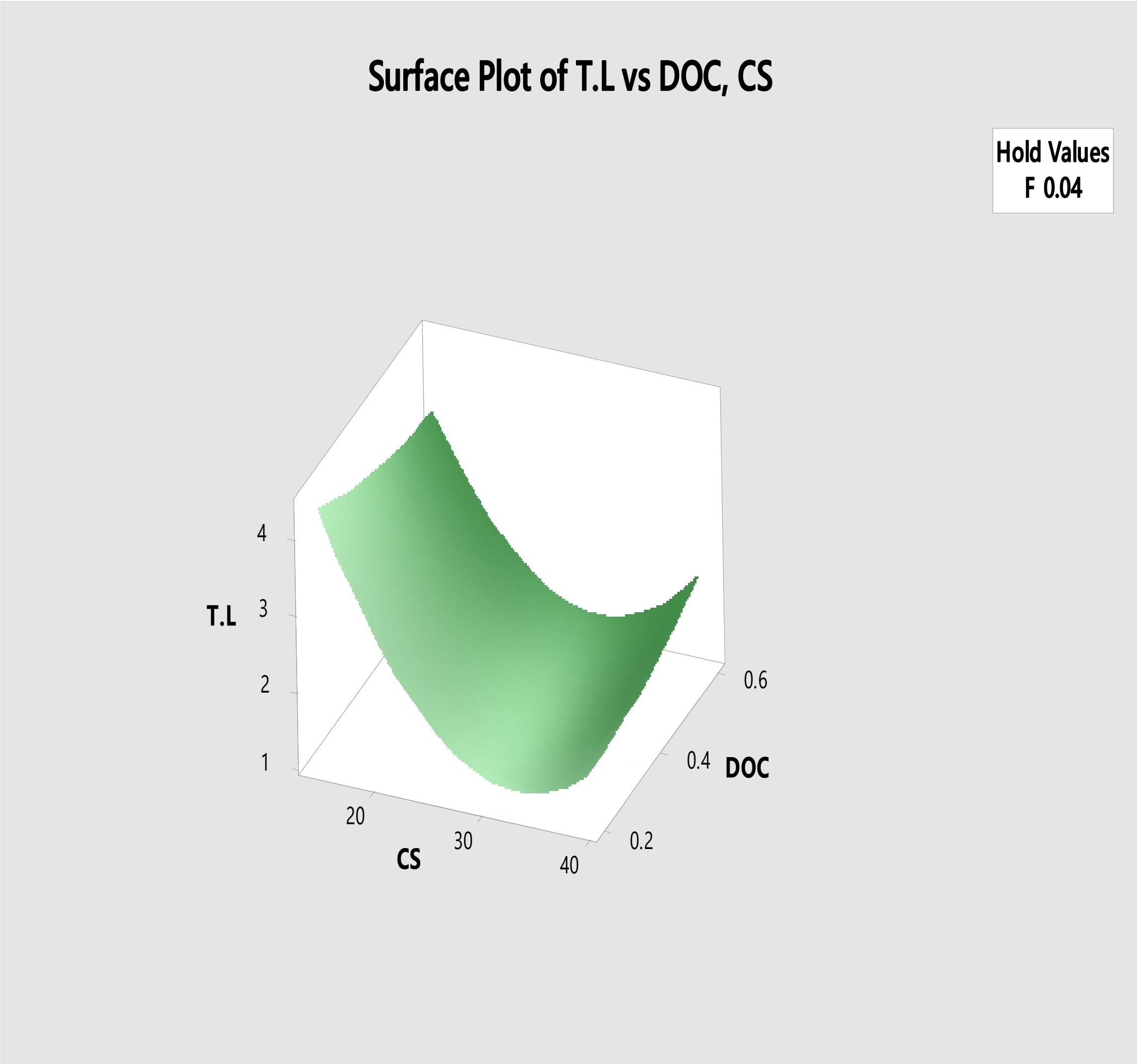
The surface plot of flank wear vs feed and depth of cut gives relationship between flan wear, depth of cut and feed.From the graph it can be observed that flank wear is highest when feed is minimum and depth of cut is maximum.



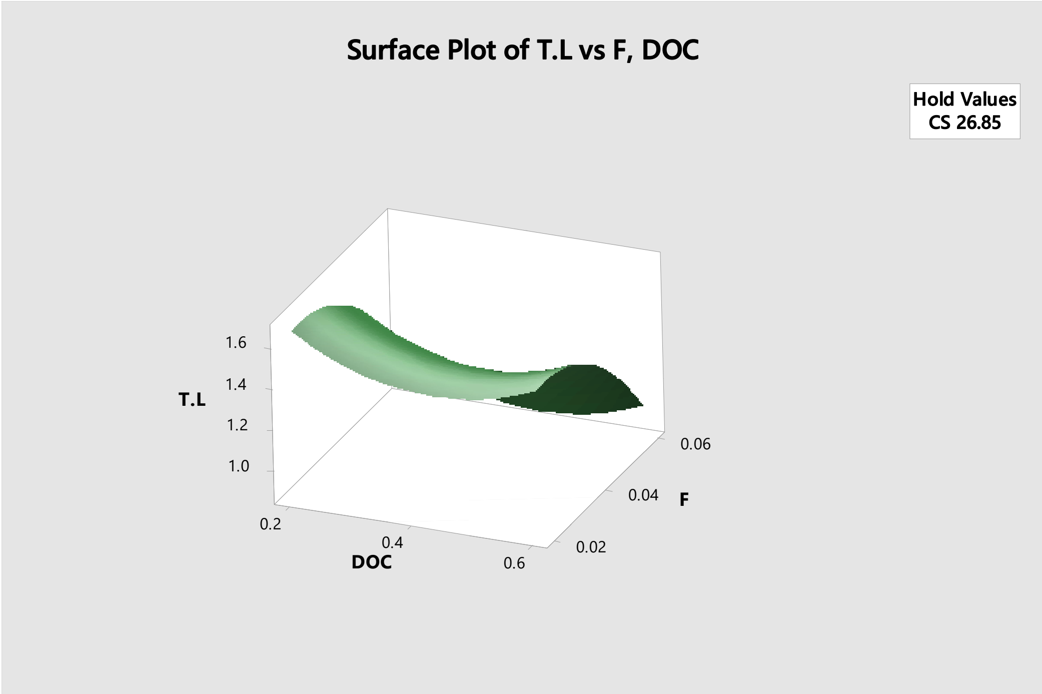
The surface plot of flank wear vs cutting speed and feed gives relationship between flank wear cutting speed and feed.From the graph it can be observed that flank wear is minimum when cutting speed and feed are minimum.



The surface plot of tool life vs cutting speed and feed gives relationship between tool life ,speed and feed. From the graph the tool life is maximum when cutting speed and feed are minimum.



The surface plot of tool life vs cutting speed and depth of cut gives relationship between tool life ,speed and depth of cut. From the graph the tool life is maximum when cutting speed and depth of cut are minimum.



The surface plot of tool life vs depth of cut and feed gives relationship between tool life ,depth of cut and feed. From the graph the tool life is maximum when depth of cut and feed are minimum.

Chapter 7
Conclusion

Chapter 7

Conclusion

In this study, the Grey-based Taguchi method was applied for the multiple performance characteristics of drilling operations. Multi-response optimization of turning process has been used to obtain optimal parametric combination that provides the minimum cutting force, flank wear, displacement with the maximum tool life.

The application of the Grey relational analysis based on the Taguchi method directly integrates the multiple quality characteristics into a single performance characteristic called Grey relational grade. Optimal combination of process parameters is evaluated considering the highest Grey relational grade by using the Taguchi method.

By applying the Taguchi method the number of experiments is drastically reduced. A L9 Taguchi orthogonal array, the signal to noise (S/N) ratio and the analysis of variance (ANOVA) were used for the optimization of cutting parameters considering Grey relational grade. According to the analysis the optimal parameter combination for drilling of the AL6082 regarding multiple performance characteristics were levels: A-level 1, B-level 1, and C-level 2. Namely, cutting speed of V = 14.5 m/min, feed rate of f = 0.02 mm/rev and depth of cut d = 0.4 mm.

The results ANOVA indicates that the percentage contribution of individual process parameters of drilling process for 'cutting force'. The percentage contribution of cutting speed, N is 93.023 %, Feed rate, f is 2.0789 %, Depth of cut is 2.0789 % and error is of 2.81 % . The error obtained is due to machine vibration during high speed drilling.

The percentage contribution of individual process parameters of drilling process for 'Displacement'. The percentage contribution of cutting speed, N is 57.336 %, Feed rate, f is 41.133 %, Depth of cut is 41.133 % and error is of 39.601 %

The percentage contribution of individual process parameters of drilling process for 'FLANK WEAR'. The percentage contribution of cutting speed, N is 59.375 %, Feed rate, f is 39.699%, Depth of cut is 39.699 % and error is of 38.773 %.

The percentage contribution of individual process parameters of drilling process for 'TOOL LIFE'. The percentage contribution of cutting speed, N is 85.714 %, Feed rate, f is 11.238%, Depth of cut is 11.238% and error is of 8.191 %. The error obtained is due to machine vibration during high speed drilling.

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