ESTIMATION OF THRUST FORCES IN DRILLING OF EN8 MATERIAL BY USING RESPONSE SURFACE METHODOLOGY IN WET AND DRY CONDITIONS

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Abstract
The main objective of this work deals with the effect of cutting parameters on EN8(080M40) carbon steel specimen in drilling operation to optimize the cutting forces using surface response analysis. Now a days EN8 is used in many engineering applications such as manufacturing of shafts, gears, stressed pins, studs, bolts, keys etc., due to its good tensile strength.

In the present work full factorial design is considered with process parameters such as speed, feed, and diameter of drill bit. By using mathematical model the main and interaction effect of various process parameters on cutting forces are studied. The developed model helps in selection of proper machining parameters for specific material and helps in achieving minimum cutting forces in two different conditions dry and wet (using cutting fluids).
Keywords: Cutting Forces, Full Factorial Design, Response Surface Methodology, EN8

INTRODUCTION

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 multipoint. 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 from the hole as it is drilled.

- The machine used for drilling is called drilling machine.
- The drilling operation can also be accomplished in lathe, in which the drill is held in tailstock and the work is held by the chuck.
- The most common drill used is the twist drill.

DRILLING OPERATION

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

Speed:

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

$$V=\pi DN/1000$$

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

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

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

Feed:

Feed always refers to the cutting tool, and it is the rate at which the tool advances along its cutting path. On most power-fed machines, 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.

Fm =f x N (mm/min)

Here, fm is the feed in mm per minute

f- Feed in mm/rev and

N - Spindle speed in r.p.m.

Depth of Cut:

Depth of cut is practically self- explanatory .It is the thickness of the layer being oved (in a single pass) from the workpiece or the distance from the uncut surface of work to the cut surface, expressed in mm. It is important to note, though, that the diameter of the work piece is reduced by two times the depth of cut because this layer is being removed from both sides of the work

$$Dcut = \frac{D - d}{2}$$

Dcut - Depth of cut in mm

D - Initial diameter of the work piece

d - Final diameter of the work piece

Drill bit:

Drill bits are cutting tools used to remove material to create holes, almost always of circular cross-section. Drill bits come in many sizes and shape and can create different kinds of holes in many different materials. In order to create holes drill bits are attached to a drill, which powers them to cut through the workpiece, typically by rotation. The drill will grasp the upper end of a bit called the shank in the chuck.

Drill bits come in standard sizes, described in the drill bit sizes article. A comprehensive drill bit and tap size chart lists metric and imperial sized drill bits alongside the required screw tap sizes. There are also certain specialized drill bits that can create holes with a non-circular cross-section. To drill a satisfactory hole in any material, the correct type of drill bit must be used; it must be used correctly and be sharpened as appropriate. Many jobs around the house require a hole of some kind to be drilled - whether it is putting up a shelf, building a cabinet or hanging a light fitting. For basic requirements, a set of high-speed steel twist drills and some masonry bits will probably be sufficient for the average handyman. But for more sophisticated jobs/material, others bits will be required - perhaps larger, or designed for a specific material/purpose. Good quality drill bits can be expensive, so take care of them, keep them in a case or box if possible, rather than allowing them to roll around loose in a toolbox where the cutting edges may be damaged. Learning how to sharpen drill bits is cost effective, it better to keep a bit sharp by occasional sharpening rather than waiting until it becomes really blunt. A sharp bit cuts better with less effort whether used in a power or hand drill. A sharp bit will also give a cleaner hole.

Twist bits: Usually referred to as twist drills, twist bits are probably the most common drilling tools used by the handyman with either a hand or electric drill. The front edges cut the material and the spirals along the length remove the debris from the hole and tend to keep the bit straight. They can be used on timber, metal, plastics and similar materials. Most twist bits are made from following

- High speed steel :(HSS) these are suitable for drilling most types of material, when drilling metal the HSS stands up to the high temperatures. High Speed Steel is a high carbon tool steel, containing a large dose of tungsten. A typical HSS composition is: 18%tungsten, 4% Chromium, 1% Vanadium, 0.7% carbon and the rest, Iron. HSS tools have a harness of 62-64 Rc. The addition of 5 to 8% cobalt to HSS imparts higher strength and wear resistance

- Carbon steel: these bits are specially ground for drilling wood and should not be used for drilling metals; they tend to be more brittle, less flexible than HSS bits.

- Low Carbon Steel – Composition of 0.05%-0.25% carbon and up to 0.4% manganese. Also known as mild steel, it is a low-cost material that is easy to shape. While not as hard as higher-carbon steels, carburizing can increase its surface hardness.
- Medium Carbon Steel – Composition of 0.29%-0.54% carbon, with 0.60%-1.65% manganese. Medium carbon steel is ductile and strong, with long-wearing properties.
- High Carbon Steel – Composition of 0.55%-0.95% carbon, with 0.30%-0.90% manganese. It is very strong and holds shape memory well, making it ideal for springs and wire.
- Very High Carbon Steel - Composition of 0.96%-2.1% carbon. Its high carbon content makes it an extremely strong material. Due to its brittleness, this grade requires special handling.

Twist bits are also available coated with Titanium nitride (TiN), these are easily identified by the gold like colour. This coating increases the hardness of the bit and adds a self-lubricating property. The coating is only really effective when metal is being drilled, it has little effect when working with other materials. Twist drills are usually available in sizes 0.8-12 mm plus. They are designed for drilling relatively small holes; they sometimes tend to clog quickly especially when the wood is 'green' so when drilling deep holes (especially in hardwood) the bits should be withdrawn regularly to remove the waste. Special care is required when using the smallest sizes since these bits are thin and brittle. Always hold the drill square to the work and apply only light pressure when drilling.

Sharpening - use a drill sharpener, a grindstone jig or an oilstone. Titanium nitride bits cannot be sharpened without destroying the coating (although if the drill needs sharpening, the coating will probably have already been destroyed). Forming the correct angle at the tip is important for efficient cutting.

SELECTION OF MATERIAL

By studying various projects EN8 (080M40) material is selected for machining operation because of its high tensile strength. The composition of EN8 is:

- Carbon- 0.36-0.44%
- Manganese- 0.6-1.0%
- Phosphorous- 0.05%
- Sulphur- 0.005%
- Silicon- 0.10-0.40
- Standard: BS 970-1971

The dimensions of the work piece used are thickness 15.5 mm*50mmdia

LITERATURE REVIEW

Future resource developments are subject to drill in cost efficient manners. For that reason future management of drilling operations will face new hurdles to reduce overall costs, increase performances and reduce the probability of encountering problems. Drilling for energy search from the ground has shown considerable technological advances in the recent years. Different methods from different disciplines are being used nowadays in drilling activities in order to obtain a safe, environmental friendly and cost effective well construction. Communication and computer technologies are among the most important disciplines which can contribute to drilling optimization. Large amount of data could be piped through different locations on the planet in reliable and time efficient manners. Advanced computer technologies are now being used in storing large amounts of data, and solving complex problems. From the very early beginning of the drilling campaigns the operators have always been seeking to reduce the drilling costs mainly by increasing the drilling speed. In the drilling industry, with increasing familiarity to the area optimized drilling could be implemented decreasing costs of each subsequent well to be drilled until a point is reached at which there is no more significant improvement [1]. The relationship among drilling parameters are complex, the effort is to determine what combination of operating conditions result in minimum cost drilling [2]. The generally accepted convention for a proper planning of any drilling venture is to optimize operations and minimize expenditures [3]. Another essential aspect of the optimization is to enhance the technology and make the system effective [4]. Recently environmental friendly activities have also started to be common practice in certain locations, which in turn could be achieved by means of reducing the risks associated with having technical problems. In recent years the increasing emphasis that is being paid by the oil and gas field operator companies towards working much efficiently at the rig sites are based on some important reasons. The most important of all are: cost and trouble free operations. During a peak in the cost of hydrocarbon resources, the rig supplier and oil field service provider contractor charges are increasing, pushing operators to work efficiently. Due to the complexity of the activities being offshore and/or being in the form clusters operators restraining themselves from causing a damage, which may result in destruction of more than one well due to their proximity between each other being very close. Directional techniques allowed drilling multiple from one location, thus eliminating construction of expensive structures for each well [5]. Due to the drilling requirements similarity of the located at close distances, collecting past data, and utilizing in a useful manner is considered to have an important impact on drilling cost reduction provided that optimum parameters are always in effect. Major drilling variables considered to have an effect on drilling rate of penetration (ROP) are not fully comprehended and are complex to model [6]. For that very reason accurate mathematical model for rotary drilling penetration rate process has not so far been achieved. There are many proposed mathematical models which attempted to combine known relations of drilling parameters. The proposed models worked to optimize drilling operation by means of selecting the best bit weight and rotary speed to achieve the minimum cost. Considerable drilling cost reductions have been achieved by means of using the available mathematical models. It is important to bear in mind that formation properties, which are uncontrollable are one of the most critical factors in drilling performance determination. Drilling fluid properties and bit types, though controllable are not in good drilling practice to changes in ordinary bit runs. However, hydraulics, the weight applied to the bit and bit and rotary speed are among the controllable factors. The scope of this study is to make use of the data from rig sites. The data available to the drilling engineer is mainly sourced from Mud Logging Units (MLU). It is also known that recently manufactured rigs are being equipped with powerful data import capabilities that make connection to third-party ite Information Transfer Specification (WITS) data simple and reliable [7]. WITS is a communications format used for the transfer of a wide variety of bit data from one computer system to another. It is a recommended format by which Operating and Service companies involved in the Exploration and Production areas of the Petroleum Industry may exchange data in either an online or batch transfer mode [8]. New generation tool is bit Information Transfer Standard Markup Language (WITSML) which is the standard transmission of bit data in a consistent form which would enable the integration of information from different suppliers [9,10]. The data could be piped in real-time, be processed and interpreted such as to recommend the optimum drilling parameters back in real-time as well. This cycle is easily achievable in today's technology by means of using advanced communication systems, and innovative computer technologies. In order to understand what has been done so far in regards to drilling optimization it is very important to see what has been performed in the recent history.

EXPERIMENTAL SETUP AND MACHINING

The work was done in 3 stages.

- Design of experiments was done using full factorial method.
- Observation and calculation of cutting forces, temperature, material removal rate by machining the work piece on Radial drilling machine in both wet and dry conditions.
- Analysis of results was done using MINITAB 15.1.30.

Experimental setup of drilling

Selection of process variables

- A total of three process variables and 2 levels are selected for the experimental procedure.
- The deciding process variables are
    - Speed
    - Feed
    - Diameter of drill bit

- Speed of the spindle, i.e. the speed at which the spindle rotates the tool.
- Feed is the rate at which the material is removed from the work piece.
- Diameter of drill bit is the diameter of the hole to be drilled on the work piece.

Selection of levels:

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

FACTORS	LEVEL1	LEVEL2
S.SPEED(RPM)	180	112
FEED(MM/REV)	0.21	0.13
DIAMETER OF DRILL BIT(MM)	14	12

Selection of process variables

Design of Experiments

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

Machining of the work piece

The machining of the work piece on RADIAL DRILLING MACHINE is done by using the following procedure

- Selection of material
- Clamping of the work piece
- Clamping of the cutting tool
- Drilling of the work piece

RESULTS AND DISCUSSIONS

Development of Mathematical Models:

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

$$Y = \beta + \beta 1\ x1 + \beta 2\ x2 + \ldots.\_\ \beta x\ xx + \in$$

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

- Y is the corresponding response
- Xi are the cutting parameters
- (1,2,…….k) are code levels of quantitative process variables
- The terms are the second order regression coefficients
- Second term is attribute to linear effect
- Third term corresponds to higher order effects
- Fourth term includes the interactive effects of the process parameters.
- And the last term indicates the experimental error.
- All the estimated coefficients were used to construct the models for the response parameter and these models were used to construct the models for the response parameter and these models were tested by applying Design of Experiments (DOE) response surface methodology.

Different Terms used in Response Surface Methodology Regression table

1. P-values: P- Values (P) are used to determine which of the effects in the model are statistically significant.
   - If the p-value is less than or equal to 0.5, conclude that the effect is significant.
   - If the p-value is greater than 0.5, conclude that the effect is not significant.

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

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

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

5. Estimated coefficients using un coded units

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

Graphs Obtained

1. Histogram:

A Histogram is a graphical representation of the distribution of data. It is an estimate of the probability distribution of a continuous variable(quantitative variable) and was first introduced by Karl Pearson .The Histogram is the most commonly used graph to show frequency distributions. Histograms give a rough sense of the density of the data, and often for density estimation estimating the probability density function of the underlying variable. The total area of a histogram used for probability density is always normalized to 1.If the length of the intervals on the X-axis are all 1, then a histogram is identical to a relative frequency plot.

2. Normal plot of residuals:

It shows the graph plotted between the residuals versus their expected values when the distribution is normal. The residuals from the analysis should be normally distributed. In practice, for balanced ort nearly balanced designs or for data with large number of observations, moderate departures from normality do not seriously affect the results. The normal probability plot of the residuals should roughly follow a straight line.

Design of Experiments in Coded form:

Expt NO	S.Speed (rpm)	Feed (mm/rev)	Diameter of drill bit(mm)
1	+1	+1	+1
2	+1	-1	+1
3	+1	+1	-1
4	+1	-1	-1
5	-1	+1	+1
6	-1	-1	+1
7	-1	+1	-1
8	-1	-1	-1

Design of Experiments in uncoded units:

Speed (rpm)	Feed(mm/rev)	Diameter of drill bit(mm)
180	0.21	14
180	0.13	14
180	0.21	12
180	0.13	12
112	0.21	14
112	0.13	14
112	0.21	12
112	0.13	12

Response Surface Regression: Thrust versus Speed, Feed & Dia

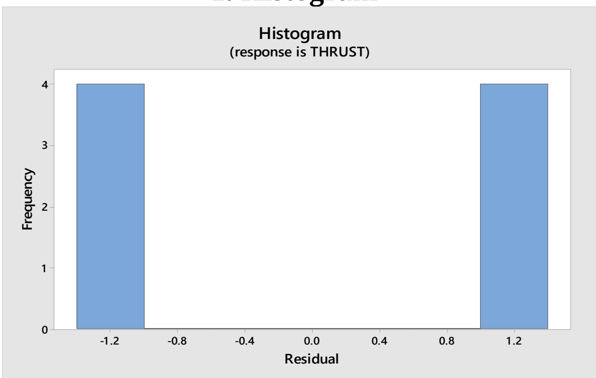
DRY CONDITION Coded Coefficients

Term	**Coef**	**SE Coef**	**T-Value**	**P-Value**	**VIF**
Constant	58.63	1.13	52.11	0.012	1.00
SPEED	-2.38	1.13	-2.11	0.282	1.00
FEED	7.87	1.13	7.00	0.090	1.00
DIAMETER	11.12	1.13	9.89	0.064	1.00
SPEED*FEED	0.88	1.13	0.78	0.579	1.00
SPEED*DIAMETER	0.62	1.13	0.56	0.677	1.00
FEED*DIAMETER	3.37	1.13	3.00	0.205	1.00

Regression Equation in Un-coded Units

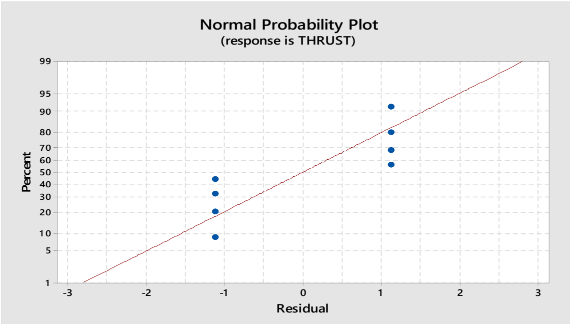
THRUST = 128.1-0.418 SPEED - 994 FEED - 5.90 DIAMETER +0.643 SPEED* FEED +0.018 SPEED*DIAMETER+84.4 FEED* DIAMETER

1. Histogram



Histogram (Thrust)

2. Normal plots of Residuals



Normal probability plot (Thrust)

List of Experimental and predicted values for Thrust

S. no	SPEED	FEED	DIAMETER	THRUST	ESTIMATED THRUST	PRECENTAGE ERROR
1	180	0.21	14	79	80.125	-1.125
2	180	0.13	14	57	55.875	1.125
3	180	0.21	12	51	49.875	1.125
4	180	0.13	12	38	39.125	-1.125
5	112	0.21	14	83	81.875	1.125
6	112	0.13	14	60	61.125	- 1.125
7	112	0.21	12	53	54.125	-1.125
8	112	0.13	12	48	46.875	1.125

Experimental and predicted values of Thrust

WET CONDITION

Response Surface Regression: Thrust versus Speed, Feed & Dia.

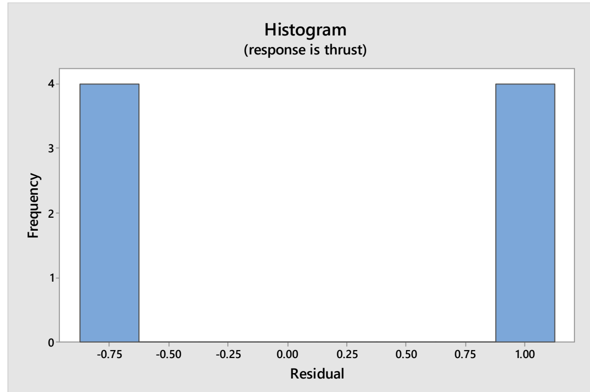
Coded Coefficients

`Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		51.87	0.875	59.29	0.011	1.0
SPEED	-0.75	-0.375	0.875	-0.43	0.742	1.0
FEED	-1.25	-0.625	0.875	-0.71	0.605	1.0
DIAMETER	5.750	2.875	0.875	3.29	0.188	1.0
SPEED*FEED	2.250	1.125	0.875	1.29	0.421	1.0
SPEED*DIAMETER	3.250	1.625	0.875	1.86	0.314	1.0
FEED*DIAMETER	-1.25	-0.625	0.875	-0.71	0.605	1.0

Regression Equation in Un coded Units

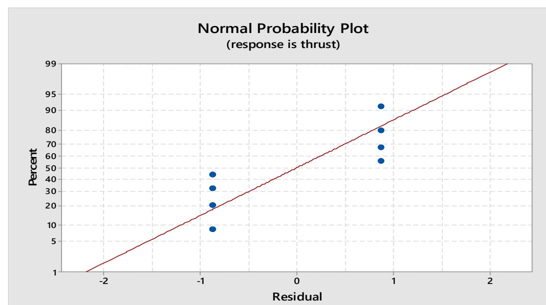
thrust = 95.5 - 0.773 speed + 67 feed
- 1.45 diameter + 0.827 speed*feed
+ 0.0478 speed*diameter
- 15.6 feed*diameter

1. Histogram



Histogram (Thrust)

2. Normal plots of Residuals



Normal probability plot (Thrust)

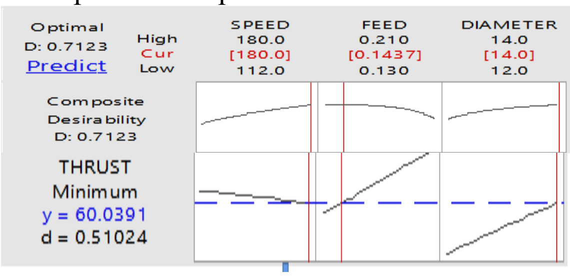
List of Experimental and predicted values for Thrust

S.no	SPEED	FEED	DIAMETER	THRUST	ESTIMATED THRUST	PRECENTAGE ERROR
1	180	0.21	14	55	55.875	- 0.875
2	180	0.13	14	57	56.125	0.875
3	180	0.21	12	49	48.125	0.875
4	180	0.13	12	45	45.875	-0.875
5	112	0.21	14	52	51.125	0.875
6	112	0.13	14	55	55.875	-0.875
7	112	0.21	12	49	49.875	-0.875
8	112	0.13	12	53	52.125	0.875

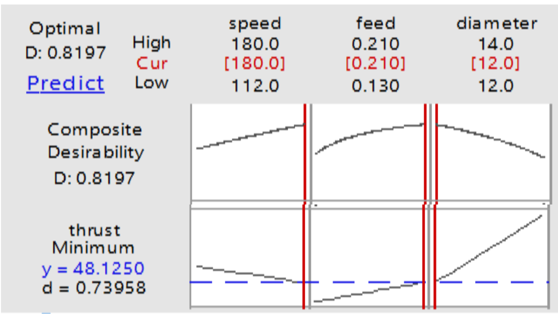
Experimental and predicted values of Thrust

CONCLUSIONS

Wet optimization plot



Dry optimization plot



In the present work, Response Optimization problem has been solved by using an optimal parametric combination of input parameters such as Speed, Feed and Diamter of the drill bit.

These optimal parameters ensures in producing high surface quality turned product.
Response Surface Methodology is successfully implemented for optimizing the input parameters.

This project produces a direct equation with the combination of controlled parameters which can be used in industries to know the Value of Surface Roughness instead of machining.
The implementation of this gives direct equation in manufacturing industries

- reduces the manual effort
- reduces the production cost
- reduces the manufacturing time.
- Increases the quality of the product which is the ultimate goal of an industry.

Dry Condition
Hence we conclude that the optimal solution for the thrust 48.1250 N to obtained when speed=180 rpm, feed=0.1437 mm/rev, and diameter of drill bit= 14.0 mm.

Wet Condition
Hence we conclude that the optimal solution for the thrust 60.0391 N to obtained when speed=180 rpm, feed=0.210 mm/rev, and diameter of drill bit= 12.0 mm by using BPCL oil

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