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Effect of Cutting Parameters in Drilling of EN8 (080M40) Carbon Steel to Obtain Maximum MRR and Minimum Temperature by Using RSM (Under Dry Condition)

B. Pradeep Kumar[1], Dr. N.V.N. Indra Kiran[2], S. Phani Kumar[3]

[1,3]Assistant Professor, Department of Mechanical Engineering, ANITS, Visakhapatnam, Andhra Pradesh, INDIA

[2]Professor, Department of Mechanical Engineering, ANITS, Visakhapatnam, Andhra Pradesh, INDIA

ABSTRACT

The main objective of this work deals with optimization of cutting parameters on EN8(080M40) carbon steel specimen in drilling operation to obtain Maximum Material Removal Rate(MRR), and Minimum work piece temperature using surface response analysis under dry conditions. Now a day's EN8 (080M40) carbon steel is widely used in manufacturing of shafts, gears, stressed pins, studs, bolts, keys etc., due to its high weight to strength ratio. In the present work Full Factorial Design is considered with three process parameters: Speed, Feed and Depth of cut. By using the mathematical model the main and interaction effect of various process parameters on MRR and Temperature are studied. The developed model helps in selection of proper machining parameters for the specific material and also helps in achieving the desired Material Removal Rate and minimum Temperature.

***Keywords*—** Material Removal Rate, Cutting Forces, Design of Experiments, Response Surface Methodology

I. DRILLING OPERATION

Drilling is a cutting process that uses a drill bit to cut a hole of circular cross-section in solid materials as shown in fig 1.1. The drill bit is usually a rotary cutting tool, often multipoint. The bit is pressed against the workpiece and rotated at rates from hundreds to thousands of revolutions per minute. This forces the cutting edge against the workpiece, 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.

Fig 1: Drilling Operation

1.1 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 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 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 drilling in m/min, D is the initial diameter of the work piece in mm, N is the spindle speed in r.p.m.

1.3 Feed

Feed always refers to the cutting tool, and it is the rate at which the tool advances along its cutting path. On most power-fed lathes, the feed rate is directly related to the spindle speed and is expressed in mm (of tool advance) per revolution (of the spindle), or mm/rev.

F_m= f x N *(mm*/min)

Here, F_m is the feed in mm per minute, f - Feed in mm/rev and

N - Spindle speed in r.p.m.

1.4 Depth of Cut

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

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

D_{cut} - Depth of cut in mm

D - Initial diameter of the work piece

d - Final diameter of the work piece

1.5 Metal Removal Rate

It is the amount of material removed per unit time i.e., volume of material removed per unit time. Material removal rate is given by

$$MRR= \frac{\prod(D^2 - d^2)*f}{4}$$

D is the initial diameter of the work piece d is the final diameter of the work piece f is feed in mm/min

1.6 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 17- 5% vanadium. Most grades contain about 0.5% molybdenum and most grades contain 4 - 12% cobalt.

1.7 EN8 (080M40) Carbon Steel:

Studying various projects EN8 (080M40) carbon steel is selected for machining operation. The composition of EN8(080M40) carbon steel 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 workpiece used are thickness 15.5 mm*50mmdia

II. LITERATURE REVIEW

B. P. Patel .et.al[1] , studied experimentally the cutting parameters required to optimize the Geometric dimensions and tolerance (GD&T) requirements such as perpendicularity. This paper reports an experimental investigation of a full factorial design performed on EN8 and EN31 materials using HSS drill with point angle 118° and helix angle 30° by varying the drilling parameters such as spindle speeds, feed and coolant ratio to determine optimum cutting conditions. The work piece Geometric dimensions and tolerance (GD&T) requirements analyzed by perpendicularity. Analysis of variance (ANOVA) was carried out for perpendicularity on EN8 and EN31 materials and their contribution rates was determined. Design of Experiments (DOE) methodology by full factorial Design was used in the multiple objective optimizations (using Mini Tab 16, software) to find the optimum cutting conditions for least perpendicularity defect.

Babur Ozcelik .et.al[2] , showed Effects of vegetable based cutting fluids on the wear in drilling. They worked on semi-synthetic commercial cutting fluid, sun - flower and canola oils. Their Experimental results show that canola based cutting fluid gives the best performance due to its higher lubricant properties with respect to other cutting fluids at the constant cutting conditions.

E. Kuram .et.al[3] , they investigate the effects of cutting fluid types and cutting parameters on surface roughness and thrust force and concluded that an increase in the spindle speed decreased the thrust force value and surface roughness value and increase in feed rate increased the force value and surface roughness value.

Asst.Prof.J.Patel .et.al[4] , investigated on effect of cutting parameter on drilling operation for perpendicularity and based on research paper they concluded that by using proper optimization method like Taguchi method, Design Of Experiment(DOE) and efficient software like (Mini tab 16,Analysis of variance[ANOVA]), we can obtain optimum response parameters such as surface roughness, perpendicularity, cylindricity and circularity .

S.Sathiyaraj .et.al[5] , they investigated on optimization of machining parameters for EN8 Steel through Taguchi method and conclude that cutting speed has most dominant effect on the observed surface roughness, followed by feed rate and depth of cut, whose influences on surface roughness are smaller.

Gultekin Uzun .et.al[6] , In this study, the effect of different foaming durations on the pore structure of Al foam material was examined and the foaming duration for homogenous pore distribution was determined. The obtained samples were drilled with drills of different diameters at different feed rates and cutting speeds. Feed forces increased with the increase in cutting speed. Feed force exhibited increases in the interval 200–500 % with the increase in feed amount. Foamed structure affected the chip breakings causing an increase in chip adhesions proportionally with the cutting speed.

***Mr. T Bharadwaj .et.al*[7]1** , they showed optimization of process parameters in drilling EN8 steel using Taguchi technique and gave conclusion that Surface roughness increases with increase in feed, increase in depth of hole while with spindle speed, surface roughness initially decreases as the spindle speed increases from 360 RPM to 490 RPM and surface roughness increases with increase in spindle speed from 490 RPM to 680 RPM and all the three independent parameters (spindle speed, feed and depth of hole) seem to be the influential drilling parameters that affect the surface roughness.

III. EXPERIMENTATION

3.1 Design of Experiments

Design of Experiments is an experimental or analytical method that is commonly used to statistically signify the relationship between input parameters to output responses. DOE has wide applications especially in the field of science and engineering for the purpose of process optimization and development, process management and validation tests. DOE is essentially an experimental based modeling and is a designed experimental approach which is far superior to unplanned approach whereby a systematic way will be used to plan the experiment, collect the data and analyze the data. A mathematical model has been developed by Response Surface Methodology. Optimization and Desirability functions helps to optimize the quality characteristics considered in a DOE under a cost effective process.

3.2 Process Variables

Three Process variables Known as factor in Design of Experiments are Speed, Feed and Depth of Cut are displayed in Table 3.1 in three levels. **Table 3.1: Process variables and their limits**

Table 3.1: Selection of process variables

Factors	Level1	Level2
S.Speed(Rpm)	180	112
Feed(Mm/Rev)	0.21	0.13
Diameter Of Drill Bit(Mm)	14	12

3.3 Minitab Software

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 MNITAB, a statistical analysis program by NIST. Minitab is distributed by Minitab Inc, a privately owned company headquartered in State College. Pennsylvania, with subsidiaries in Coventry, England, Paris, France and Sydney, Australia Today, Minitab is often used in conjunction with the implementation of Six sigma, CMMI and other statistics-based process improvement methods.

3.4 Full Factorial Method

Experiments have been carried out using full factorial method. Experimental design which consists of 27 combinations of spindle speed, longitudinal feed rate and depth of cut. According to the design catalogue prepared by factorial design of experiment has been found suitable in the present work. It considers three process parameters (without interaction) to be varied in three discrete levels. The experimental design has been shown in Table 3.2 (all factors are in coded form). Factorial design is used for conducting experiments as it allows study of interactions between factors. Interactions are the driving force in many processes.

Table 3.2 DOE 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

IV. RESUTS AND DISCUSSIONS

4.1 Response Surface Methodology

Response surface methodology uses statistical models, and therefore practitioners need to be aware that even the best statistical model is an approximation to reality. In practice, both the models and the parameter values are unknown, and subject to uncertainty on top of ignorance. Of course, an estimated optimum point need not be optimum in reality, because of the errors of the estimates and of the inadequacies of the model. Nonetheless, response surface methodology has an effective track-record of helping researchers improve products and services: For example, Box's original response-surface modeling enabled chemical engineers to improve a process that had been stuck at a saddle-point for years. The engineers had not been able to afford to fit a cubic three-level design to estimate a quadratic model, and their biased linear -models estimated the gradient to be zero. Box's design reduced the costs of experimentation so that a quadratic model could be fit, which led to a (long-sought) ascent direction.

4.2 Mathematical model of Response Surface Methodology

The Response Surface is described by an second order polynomial equation of the form

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_o x_o + \sum_{i=1}^{k} \beta_{ii} x_{i2} + \sum \sum_{i<j} \beta_{ij} x_i x_j + \epsilon$$

Y is the corresponding response

(1, 2, . . . , S) are coded levels of S quantitative process variables,

The terms are the second order regression coefficients,

Second term is attributable to linear effect, Third term corresponds to the higher-order effects, Fourth term includes the interactive effects, The last term indicates the experimental error.

4.3 Mathematical Relationship between the Input Parameters and Metal Removal Rate

The mathematical relationship for correlating the Metal removal rate and the considered process variables has been obtained as follows

MRR = -92.5 + 0.342 Speed + 294 Feed + 5.62 Diameter -0.011speed*Feed-0.0137speed*Diameter - 11.8feed*Diameter

S.No	Speed	Feed	Diameter	MRR	Estimated MRR	Precentage Error
1	180	0.21	14	39.01	39.67	-0.66
2	180	0.13	14	30.19	29.53	0.66
3	180	0.21	12	39.01	38.35	0.66
4	180	0.13	12	25.66	26.32	-0.66
5	112	0.21	14	30.3	29.64	0.66
6	112	0.13	14	18.78	19.44	-0.66
7	112	0.21	12	25.79	26.45	-0.66
8	112	0.13	12	15.02	14.36	0.66

4.3.1 Histogram

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 lengths of the intervals on the X-axis are all 1, then a histogram is identical to a relative frequency plot.

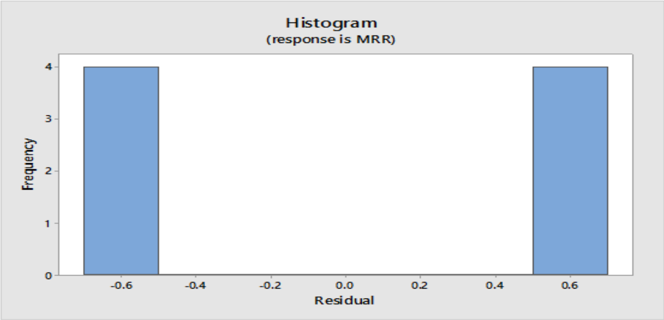

Fig- 4.1 Histogram for MRR

4.3.2 Normal Probability Plot for MRR

The normal probability plot in the Fig:4.2 shows a clear pattern (as the points are almost in a straight line) indicating that all the factors and their interaction given in are affecting the MRR. In addition, the errors are normally distributed and the regression model is well fitted with the observed values.

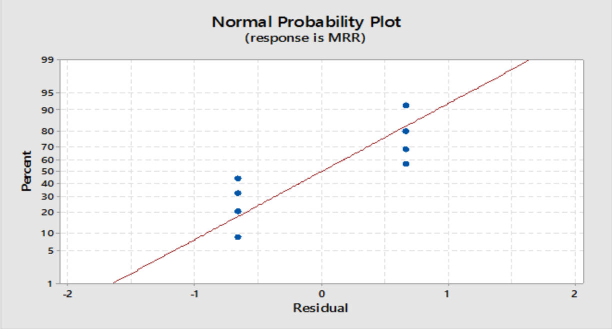

Fig: 4.2 Normal Probability Plot for MRR

4.3.3 Standardized Residual Vs Fitted Value for MRR

Fig: 4.2 indicates that the maximum variation which shows the high correlation that exists between fitted values and observed values. Table 5.6 shows pattern of the curves plotted between residual and fitted value.

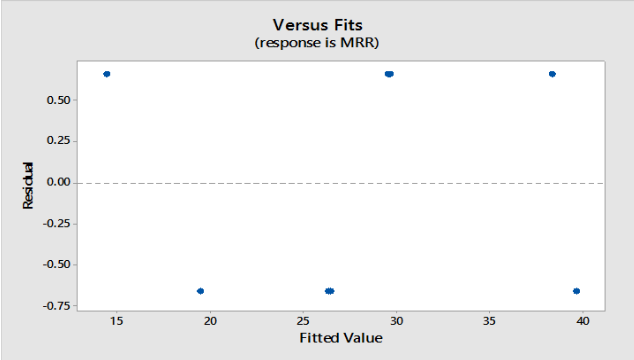

Fig: 4.3 Residual Vs Fitted Value for MRR

4.4 Mathematical Relationship between the Input Parameters and Temperature

The mathematical relationship for correlating the Temperature and the considered process variables has been obtained as follows

Temp = -37 + 1.203 Speed + 726 Feed + 5.2 Diameter - 1.93 Speed*Feed- 0.0684 Speed*Diameter- 40.7 Feed*Diameter

4.4.1 Histogram

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 lengths of the intervals on the X-axis are all 1, then a histogram is identical to a relative frequency plot.

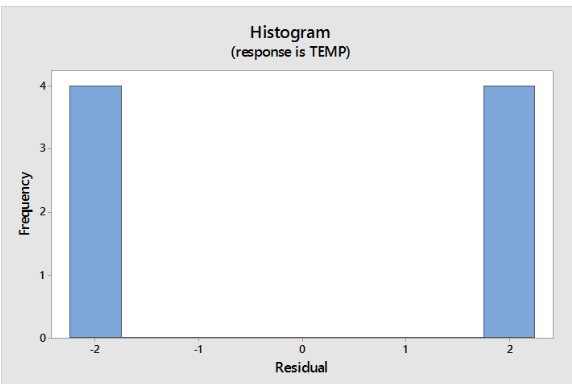

Fig- 4.5 Histogram for Temperature

4.4.2 Normal Probability Plot for Temperature

The normal probability plot in the Fig: 4.6 shows a clear pattern (as the points are almost in a straight line) indicating that all the factors and their interaction given in are affecting the Temperature. In addition, the errors are normally distributed and the regression model is well fitted with the observed values.

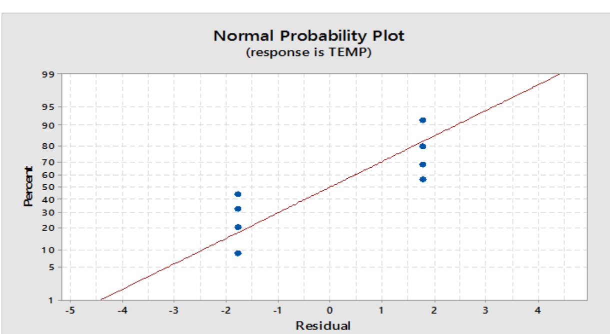

Fig: 4.6 Normal Probability Plot for Temperature

4.4.3 Standardized Residual Vs Fitted Value for Temperature

Fig: 4.7 indicates that the maximum variation which shows the high correlation that, exists between fitted values and observed values.

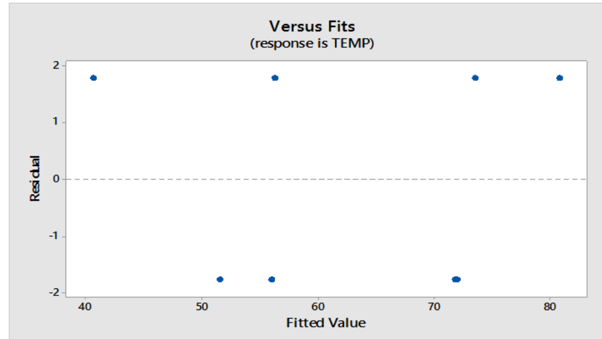

Fig: 4.7 Residual Vs Fitted Value for Temperature

4.5 Optimization Plot:

A Minitab Response Optimizer tool shows how different experimental settings affect the predicted responses for factorial, response surface, and mixture designs. Minitab calculates an optimal solution and draws the plot. The optimal solution serves as the starting point for the plot. This optimization plot allows to interactively changing the input variable settings to perform sensitivity analyses and possibly improve the initial solution.

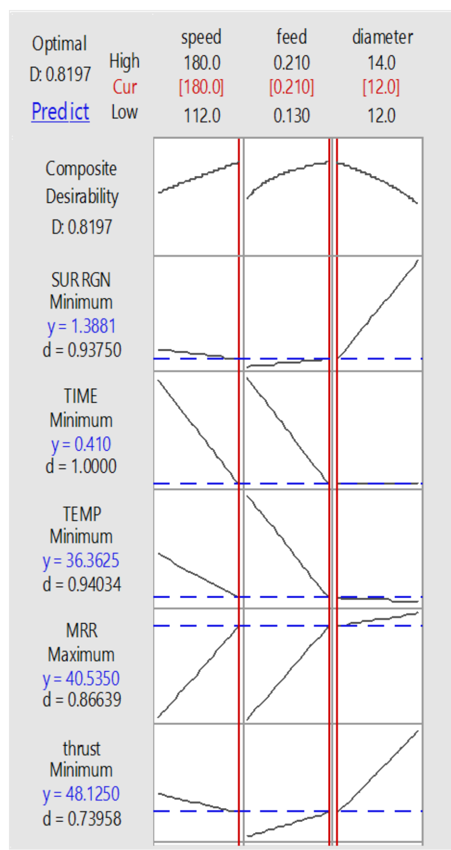

Fig: 4.8 Optimisation plot for MRR and Temperature

The optimization plot as shown in Fig: 4.10 signifies the affect of each factor (columns) on the responses or composite desirability (rows). The vertical red lines on the graph represent the current factor settings. The numbers displayed at the top of a column show the current factor level settings (in red). The horizontal blue lines and numbers represent the responses for the current factor level. Minitab calculates the maximum metal removal rate and minimum surface roughness.

From the optimization plot it can be said that the maximum metal removal rate is 40.5350 mm^3/sec and the minimum surface roughness is 1.3881µm obtained when spindle speed=180 rpm, feed=0.210 mm/rev, and diameter of 12mm.

V. CONCLUSION

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

We conclude that the maximum metal removal rate is 40.5350 mm^3/sec and the minimum surface roughness is 1.3881µm obtained when spindle speed=180 rpm, feed=0.210 mm/rev, and diameter of 12mm.

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