Optimization of Drill Bit Temperature by Response Surface Methodology (RSM)

Priyanka Gangber1 Shailendra Sahu2 Shatendra K. Sahu3 Shantosh K. Mishra4
1,2PG Student 3,4Assistant Professor
1,2,3,4Department of Mechanical Engineering

Bhilai Institute of Technology Durg, Chhattisgarh, India

Abstract— During the drilling process large amount of heat is generated. This heat affects the tool life and the behaviour of work piece material. This heat can be controlled by proper cutting parameters. In this work the effect of cutting parameters on the temperature generated during conventional drilling process is investigated using the MINITAB -17 Software. The objective of this work is to study the influence of cutting parameters (feed, cutting speed and tool type) on drill bit temperature. For this work a base paper by Ramazan & Adem [15] is selected. The optimum values of parameters for particular condition are determined. The feed rate is found to be the most affecting parameter on the drill bit temperature. The result of the work is validated by calculation and the graphical representation with the help of MINITAB17 software. The result obtained by RSM method is compared with the result obtained by Taguchi’s method and the values are approximately similar.

Key words: Drilling Process, Response Surface Methodology (RSM), Temperature Analysis, Cutting Parameter

I. INTRODUCTION

Throughout the world today, there is a continuous struggle for cheaper production with better quality. This can be achieved through optimal utilization of both material and human resources. Machining operations comprise a considerable portion of the world’s manufacturing infrastructure. They create about 15% of the value of all mechanical components manufactured worldwide. Because of its technical and economic importance, a large amount of research has been carried out in order to optimize cutting process for improving the product quality, increasing the productivity and lowering the cost of the process.

Mostly researchers concentrate on the study of wear mechanism and investigate the mathematical relationship between wear due to various wear mechanisms and some cutting process variables such as relative sliding velocity of workpiece material along tool face, cutting temperature of tool face and normal pressure on tool face.

II. LITERATURE REVIEW

Several papers have been published on prediction and measurement of temperature in the drilling process. Keizo Sakuma, Yoshimichi YOKOO works on drilling of GFRP and CFRP and determine relation between tool materials and wear behaviour [1]. Lin and Ting performed drill wear monitoring by using neural networks by measuring thrust force and torque signals [2]. Yang and Targ used Taguchi method to fine optimal cutting parameters for turning operation [3]. Chen and Taso investigated the cutting performance of different coated twist drills [4]. Yang and Chen suggested that design of experiment is an effective approach to optimize the throughput in various manufacturing related processes [5]. Bono and Ni investigated the effect of thermal distortion on the diameter and cylindricity of dry drilled holes [6]. Babur and Eyup determine the effect of drilling conditions on the twist drill temperature in dry drilling [7, 8]. Ali faraj, Dirk & Klaus [9] studied the different type of tool wear during drilling, which is “cutting edge rounding”. Anil and Singla applied Taguchi optimization methodology to optimize cutting parameters in drilling of glass fiber reinforced composite material [10]. R. Muhammad, Ahmed, Shariff & Silberschmidt determines the effect of cutting conditions on temperature generated in drilling process using finite element analysis (FEA) [11]. Nicoşor, Silviu, Virgil and Nicoale did experimental research regarding the temperature along the cutting edge of drills by using FLIR system thermo vision camera [12]. Beno and Hulling works on cutting edge temperature in drilling [13]. Pradeep and Packiaraj [14] studied the effect of drilling parameters on surface roughness, tool wear, material removal rate and error in diameter of hole in drilling of OHNS.

Ramazan and Adem perform optimization of cutting parameters on drill bit temperature in drilling by Taguchi method [15]. Boopathi, Shankar, Manikandakumar, and Ramesh performed experimental investigation of friction drilling on brass, aluminium and stainless steel [16]. Senthil kumar, Prabukarthi and Krishnaraj studied the tool wear and chip formation during drilling of CFRP stacks [17]. Sachindler Zimmermann and Aurich used finite element model to calculate thermal expansion of the tool and workpiece in dry drilling [18]. The optimization of surface integrity in drilling process using response surface method (RSM) is presented by Amran et al [19].

From the above discussion of previous research works it can be said that there are a number of parameters and conditions which can affect directly or indirectly the outcome of the drilling process. Different methods were applied by different researchers for the analysis. It is necessary to optimize the parameters in order to have desired performance of the drill tool.

III. RESPONSE SURFACE METHODOLOGY (RSM)

Response surface methodology (RSM) is a collection of mathematical and statistical techniques for empirical model building and for developing, improving, and optimizing processes. By careful design of experiments, the objective is to optimize a response (output variable) which is influenced by several independent variables (input variables). An experiment is a series of tests, called runs, in which changes are made in the input variables in order to identify the reasons for changes in the output response.

The application of RSM to design optimization is aimed at reducing the cost of expensive analysis methods (e.g. finite element method or CFD analysis) and their
associated numerical noise. The Response Surface Methodology is an important subject in statistical design of experiment. RSM is a collection of mathematical and statistical techniques useful for the modeling and analysis of problem in which a response of interest is influenced by several variables and the objective is to optimize this response.

A typical equation for RSM is given by

\[ y = f(x_1, x_2) + e \]  

The variables \( x_1 \) and \( x_2 \) are independent variables whereas the response \( y \) depends on them. The dependent variable is a function of \( x_1, x_2 \), and the experimental error term, denoted as \( e \). The surface represented by \( f(x_1, x_2) \) is called a response surface. Because the form of the true response function \( f \) is unknown, we must approximate it. In fact, successful use of RSM is critically dependent upon the experimenter’s ability to develop a suitable approximation for \( f \), usually, a low-order polynomial in some relatively small region of the independent variable space is appropriate. In many cases, either a first-order or a second order model is used.

IV. DESIGN OF EXPERIMENT

The Design of Experiment (DOE) is a very powerful tool for modelling and analyzing the effect of process variables on the response variables. The unknown factor of process variables can be termed as response variable or controllable factor. This study consists of experimentations, parametric analysis using MATLAB software and finally mathematical modeling using MINITAB 17 software. Experimentation generally specifies the machining of Al 7075 alloy bar workpiece in dry conditions on John ford CNC vertical milling machine. The data are taken from the base paper [15]. A new approach known Response surface methodology (RSM) has been used to optimize the process.

The following three machining parameters have been used to control the temperature during drilling process: cutting speed (m/min) and feed rate (mm/rev) and type of tool that is coated tool and uncoated tool. In present work these parameters were selected as design factor and other parameters have been kept constant. A Minitab generated design was used with three levels of the continuous design factors ‘feed’ and ‘speed’ and two levels of categorical design factor ‘type of tool’.

### Table 1: Assignment of the Levels to the Factors

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Machining Parameter</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Tool</td>
<td>Uncoated</td>
<td>Coated</td>
<td>---</td>
</tr>
<tr>
<td>B</td>
<td>Feed rate, ( f ) (mm/rev)</td>
<td>0.1</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>C</td>
<td>Cutting Speed ( V_c ) (m/min)</td>
<td>170</td>
<td>200</td>
<td>230</td>
</tr>
</tbody>
</table>

C. Temperature Measurement

Drill bit temperature measurements in these experiments were used K type thermocouples with a diameter of 1 mm. Measurement ranges K type (NiCr–Ni) thermocouples used in these experiments was –200º to 1200º with ±0.05% measurement accuracy [21]. The response time of the thermocouple was 10 µs. As shown in Fig. 2, the thermocouples was inserted through the coolant hole inside of the drills and the thermocouple used through the coolant hole was fixed near to the drill bit surface.

Fig. 2: Twist drilling tool and thermocouple inserted through the hole of internal coolant carbide drill [15]
V. RESULT AND DISCUSSION

The analysis of variance (ANOVA) has been used to check the adequacy of the first order model. The optimum values of the parameters were then presented for the minimum temperature of drill bit during drilling process.

A. Analysis of Variance for Temperature

ANOVA is the significant tool to analyse the result of experiment. The total variation of all the measurements around the overall mean is divided in to sources of variation that are then analysed for statistical significance. The ANOVA is shown in the Table no. 3. These values are then used to study the effect and significance of the selected cutting parameters on the response i.e. temperature.

<table>
<thead>
<tr>
<th>Source</th>
<th>Do f</th>
<th>SS</th>
<th>MS</th>
<th>F-test</th>
<th>P-value</th>
<th>PCR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tool</td>
<td>1</td>
<td>1856.6</td>
<td>1856.6</td>
<td>9.34</td>
<td>0.00</td>
<td>9.70</td>
</tr>
<tr>
<td>Feed Rate</td>
<td>1</td>
<td>10325.3</td>
<td>10325.3</td>
<td>51.9</td>
<td>0.00</td>
<td>53.0</td>
</tr>
<tr>
<td>Cutting Speed</td>
<td>1</td>
<td>2080.3</td>
<td>2080.3</td>
<td>10.4</td>
<td>0.00</td>
<td>10.6</td>
</tr>
<tr>
<td>Residual Error</td>
<td>19</td>
<td>4573</td>
<td></td>
<td></td>
<td></td>
<td>26.5</td>
</tr>
<tr>
<td>Total</td>
<td>27</td>
<td>19433.0</td>
<td></td>
<td></td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Analysis of Variance for Temperature

ANOVA is performed for a 5% (P < 0.05) significance level, i.e. for a 95% confidence level to identify the cutting parameters that affect the drill bit temperature. Statistically, F-test provided a decision at some confidence level as shown in table no. 3, for each source of variation. The F-test and the P-value illustrated that the variation of the process parameter made a big change on the performance characteristics [15]. According to table 5.1 feed rates were found to be most affecting parameter to the drill bit temperature (PCR 53.04%) and cutting speed were found to be the second important parameter (PCR 10.68%). According to the table no. 3 the tool type shows a little effect on the drill bit temperature. From Table no. 3 it is observed that, P-value for Speed is 0.000 and for feed is 0.004 which is less than 0.05 and therefore is significant. Hence feed rate is the most affecting parameter on the drill bit temperature.

B. Main effects Plot for Temperature

From the Fig. 3, Main effects plot for temperature we can clearly see that, the drill bit temperature goes on decreasing sharply as the feed rate increases. For cutting speed, the value of temperature increased with speed increases. For tool the temperature for uncoated tool is high then the temperature for coated tool.

C. Contour Plot

Contour plots are used to explore the potential relationship between three variables. Contour plots display the 3-D relationship in two dimensions, with x- and y-factors (predictors) plotted on the x- and y-scales and response values represented by contours. The dark green regions indicate higher values of response variable whereas dark blue regions indicate lower values of response variable.

D. Residual Plots for Temperature

Residual Plots are used to examine the goodness of model fit in regression and ANOVA. In fig.5, in Normal Probability plot, as all the points are falling on the straight line shows that the model is adequate and the errors are normally distributed.

E. Regression Equation

Regression Equation is an equation which is used to describe the statistical relationship between one or more predictors and the response variable and to predict new observations. The Regression Equation in uncoded units obtained by the software is:
1) Uncoated drill bit temperature (°C):
T (°C) = 166.9 - 667 feed + 0.439 cutting speed + 933 feed × feed
2) Coated drill bit temperature (°C):
T (°C) = 150.6 - 667 feed + 0.439 cutting speed + 933 feed × feed

Prediction for temperature Temperature = 158.7 - 667 feed + 0.439 cutting speed + 8.14 tool uncoated - 8.14 tool coated + 933 feed × feed

Where feed is in mm/rev and cutting speed is in m/min.

F. Surface Plot
Surface plots are used to explore the potential relationship between three variables. 3D surface plots display the three-dimensional relationship in two dimensions, with predictor variables on the x- and y-scales, and the response (z) variable represented by a smooth surface (surface plot) or a grid (wireframe plot). Surface plot in fig. 6 shows that as the feed and speed increases the value of temperature increases.

![Surface plot of temperature vs cutting speed, feed rate](image)

Fig. 6: Surface plot of temperature vs cutting speed, feed rate

G. Response Optimization
An optimal solution occurs when composite desirability reaches its maximum value. With the help of optimization plot the best optimum setting found to be: feed at level 3, speed at level 1 and tool at level 2.

![Optimization Plot](image)

Fig. 7: Optimization Plot

<table>
<thead>
<tr>
<th>Solution</th>
<th>Feed</th>
<th>Speed</th>
<th>Tool</th>
<th>Temperature fit</th>
<th>Composite desirability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.3</td>
<td>170</td>
<td>Coated</td>
<td>109.190</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 4: Response Optimizations: Temperature

H. Validation of Present Work
The present work is compared with the old work and the results are found approximate similar. The comparison table is shown in table no. 5.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Points of comparison</th>
<th>Old work</th>
<th>Present work</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Level</td>
<td>A2B3C1</td>
<td>A2B3C1</td>
</tr>
<tr>
<td>2</td>
<td>Feed rate contribution</td>
<td>56.15%</td>
<td>53.04%</td>
</tr>
<tr>
<td>3</td>
<td>Minimum temperature value</td>
<td>108.89°C</td>
<td>109.190°C</td>
</tr>
</tbody>
</table>

Table 5: Comparison between Results of Old and Present Work

VI. CONCLUSION
In this project work, the optimization of cutting parameters on drill bit temperature in drilling process by applying Response Surface Method were performed. From the above work the following points can be concluded:

1) For carrying out the successful drilling operation, the optimal speed, feed must be maintained to avoid increase in temperature and tool wear.
2) It is obtained that the feed rate and drill diameter are the parameters that make the largest contribution to the overall performance.
3) Response surface methodology is an effective tool to determine the most responsible parameter for increase in the drill bit temperature in drilling process.
4) According to ANOVA result, the most significant factor that affects the drill bit temperature was the feed rate which has the percentage contribution of 53.04%.
5) From Table no.3, it is observed that, P-value for Speed is 0.00 and for Depth of Cut is 0.000 which is less than 0.05 and therefore is significant.
6) Optimization Plot identifies the combination of input variable settings that jointly optimize the response.
7) As the composite desirability is close to 1, it can be concluded that the parameters are within their working range.
8) From the Optimization Plot Fig.5, the best optimum setting found to be: feed rate at level 3, cutting speed at level 1 and coated tool type at level 2.

REFERENCE


[9] Surface Methodology, 2nd ed. 2002