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Parametric Optimization of Temperature During CNC End Milling of Mild Steel Using RSM

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Abstract:- CNC milling is an area of interest for engineers around the world to increase the productivity, flexibility and for machining the complex shapes. In the present work, response surface methodology has been used for design of experiments during CNC end milling of mild steel material. Temperature measurement during end milling process is carried out using Cr-Al thermocouple to study the effect of various process parameters on temperature during machining. Optimization of process parameters such as cutting speed, feed and depth of cut has been carried out by ANOVA analysis using MINITAB 14.0 software. The results show the importance of parameters to optimize the temperature requirement. Conclusions made from contour plots and response surface diagrams are critically discussed.

Keywords: - Parametric Optimization of temperature, CNC End Milling, Cr-Al thermocouple, ANOVA analysis.

1. INTRODUCTION

The metal cutting technology growth rapidly and has enrolled as important aspect in manufacturing industry. In modern cutting technology, the trend continues unabated toward higher availability with more flexibility. Milling is the most important and widely useful operation process for material removal compared to turning, grinding and drilling. Milling can be defined as machining process in which metal is removed by a rotating multiple-tooth cutter with each tooth removes small amount of metal in each revolution of the spindle. Computer numerical control (CNC) milling machine is used to fabricate solid parts worldwide. Manufacturing engineers from around the world use CNC machine to produce high quality precise parts for different application [1]. CNC stands for computer numerically controlled. As a milling technique, this means that a design can be specified on a computer using cad tools, and that a computer can handle the milling process. During CNC milling the computer translates the design into instructions on how the tool needs to move to create the shape. Typically, the tool can move up down, or tilt at an angle, and the table moves the part laterally.

CNC Milling process can achieve:

- High accuracy
- Good surface quality
- Wide variety of forms and dimensions
- Low costs and high removal rates.

Y.S. Liao et al [2] conducted End milling of Inconel 718 under various cutting speeds by cemented carbide tools, and found that the increase of cutting temperature and strain hardening are responsible for the difficulty at low speed cutting. Pittalà and Monno [3] have predicted the temperature of Ti-6Al-4V work piece in Face Milling. They used infrared camera to measure the work piece temperature and then a rheological model was developed and calibrated using different milling tests. Richardson, Keavey and Dailami [4] had developed a model of cutting induced work piece temperatures during dry milling.

The knowledge on the temperature distribution in work piece is a matter of great importance due to the severe effects of intense local heat generated during machining which could affect the heat treatment or artificial aging properties, hardness and residual stresses of the material, all of which affect the fatigue life of the component [5]. Different types of methods have been developed for thermal mapping of cutting tools, work piece and chips for example: analytical methods [6], experimental and numerical (simulation) methods [7], hybrid techniques and heat source methods. Optimum selection of cutting conditions importantly contributes to decrease the temperature. More recently various artificial intelligence techniques like artificial neural network [8, 9, and 10], fuzzy logic [11] and genetic algorithm [12] are also applied on experimental results obtained from CNC milling process for optimizing different process characteristics.

In the present work, Experimental work on vertical CNC milling machine has been carried out on mild steel material. Temperature measurements using thermocouple techniques during end milling in dry condition has been performed as experimental work. Development of Response surface design for measurement of temperature during machining, and analysis of variance has been carried out using trial version of Minitab 14.0 software. Analysis of variance for different output responses such as cutting force, MRR also can be carried out using RSM as a statistical tool.

2. EXPERIMENTAL PROCEDURE

The machining tests have been carried out in a CNC vertical milling machine (DART model manufactured in Batliboi ltd., Udhna.) without coolant. The experimental set up is shown in figure 2.1(a) and (b).

Figure 2.1(a) Experimental setup

Figure 2.1(b) Experimental setup

Mild steel has been used as work piece material in the experimental tests; in the form of cube with size of 25 mm. Work pieces for experiments have been fabricated by cutting them in a cubic shape of same size and drilling holes inside them at appropriate distance. Holes drilled in work pieces were to keep thermocouple inside those holes during machining.

The experiment involved slot milling while machining. End mill cutter has been used for present work. Slot milling operation has been performed by this end mill cutter during experiments. Carbide end mill cutter having Diameters 6 mm, 8 mm, and 10 mm are used for the experiments.

Cutting speed, Feed, and depth of cut has been taken as most significant input parameters to carry out experiments.

Three levels of these parameters have been taken which are:

Table 2.1- Input parameters

Factors **Levels**	**Speed (m/min) A**	**Feed (mm/min) B**	**Depth of Cut (mm) C**
1	10	6	1
2	13	9	1.5
3	16	12	2

For the measurement of temperature, thermocouples have been used. Various types of thermocouples are available at present, amongst them K-type of chromel-alumel (Cr-Al) thermocouple has been used here to measure temperature. The operating range of this type of thermocouple is approximately -270 to 1370 °C. Thermocouple that is used here consists of two wires of different materials. Two junctions are made by brazing them at both ends, and other two free ends are connected to multimeter to measure the emf generated by temperature difference between two junctions.

One junction has been kept at 0 °C temperature (in ice cubes) as a reference junction, and other junction has been kept inside the work piece by drilling holes in the work piece. Thus by creating temperature difference between two junctions emf can be generated. This emf will be converted in °C by using standard calibration data at reference junction 0 °C for chromel-alumel thermocouple.

3. DESIGN OF EXPERIMENT

A large number of experimental works have to be carried out when the number of the process parameters increases. Therefore to reduce the number of experiments and to obtain good quality of investigation the term named Design of experiments (DOE) is getting familiar in all over the world.

Design of experiments (DOE), is one of the most important statistical tools of TQM for designing high quality systems at reduced cost. Design of Experiments (DOE) methods provides an efficient and systematic way to optimize designs for performance, quality, and cost [13]. Design of experiments (DOE) is a systematic, rigorous approach to engineering problem-solving that applies principles and techniques at the data collection stage so as to ensure the generation of valid, defensible, and supportable engineering conclusions. In addition, all of this is carried out under the constraint of a minimal expenditure of engineering runs, time, and money.

Response Surface Design is widely used DOE method. In the present design, replication and randomization of experimental runs is carried out. Each experimental run has been performed twice. Experiments have been carried out on mild steel as work piece.

There are many designs available for fitting a second-order model. The most popular one is the Central Composite Design (CCD). This design was introduced by Box and Wilson. It consists of factorial points, central points, and axial points. CCD was often developed through a sequential experimentation. When a first-order model shows an evidence of lack of fit, axial points can be added to the quadratic terms with more center points to develop CCD. The number of center points at the origin and the distance "a" of the axial runs from the design center are two parameters in the CCD design. The center runs contain information about the curvature of the surface, if the curvature is significant, the additional axial points allow for the experimenter to obtain an efficient estimation of the quadratic terms. The Figure 3.1 illustrates the graphical view of a central composite design for q = 2 factors.

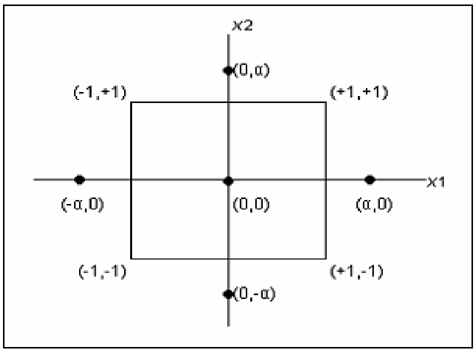

Figure 3.1 Central Composite Design for q = 2

Factors in Response Surface Design are shown in table 3.1 and used based on face centered Central Composite Design (CCD).

Table 3.1- Levels of Response Surface Design

Factors Levels	Speed (m/min) A	Feed (mm/min) B	Depth of Cut (mm) C
Low (-1)	10	6	1
High(+1)	16	12	2

In the present work, temperature is measured by taking cutting speed, feed, and depth of cut as variable control factors. All the experimental runs are performed twice after randomization and observations are used for calculating the temperature of work piece. Two sets of observations from the experimental study have been obtained and are shown in table 3.2.

Table 3.2- Observation Table

Sr. No.	Speed	Feed	Depth of Cut	Temp. (°C)	
	m/min	mm/min	mm	Trial 1	Trial 2
1	13	9	1.5	48	48
2	13	9	1.5	43	45
3	13	12	1.5	45	43
4	13	9	1.5	45	48
5	13	9	1	40	43
6	13	9	1.5	45	45
7	10	6	2	40	43
8	13	9	1.5	45	43
9	16	12	2	50	55
10	13	9	2	50	50
11	10	12	1	38	40
12	10	6	1	38	40
13	13	9	1.5	40	43
14	10	12	2	48	45
15	16	9	1.5	40	43
16	13	6	1.5	43	43
17	16	6	1	40	38
18	16	6	2	40	43
19	10	9	1.5	40	40
20	16	12	1	38	40

4. RESULTS AND DISCUSSION

After carrying out experimental study, the observations as mentioned in table 3 have been noted. Based on these observations, ANOVA analysis for temperature, main effects plot and contour plots has been obtained using trial version of MINITAB 14.0 statistical software of design and analysis.

The main effects plot for temperature has been obtained by importing all the input data and response data in statistical software.

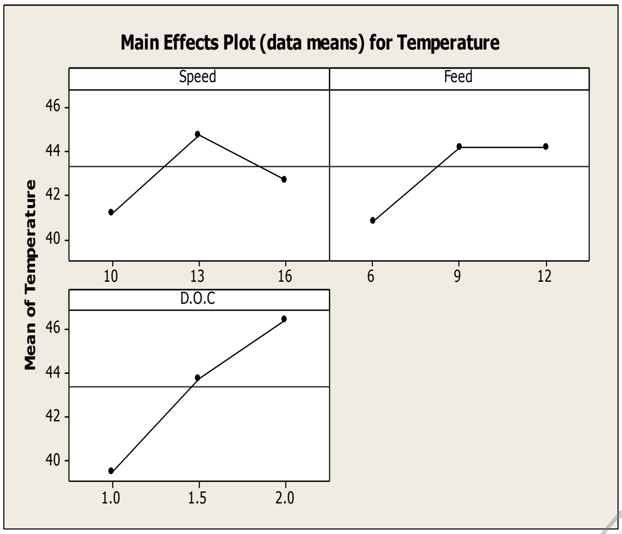

Figure 4.1 Main effects plot for temperature

Figure 4.1 shows the main effects plot for temperature. It can be seen from figure that if speed is increased then temperature would increase initially. But at higher speed temperature measurement involve some uneven trend may be due to vibration. When feed is increased, temperature would also increase. With increase in depth of cut, temperature would increase

ANOVA analysis is used to investigate process parameters, which significantly affect the quality characteristic. By importing all the data in statistical software response diagrams as well as contour plots can be developed. ANOVA analysis is shown in table 4.1.

Table 4.1- ANOVA analysis of Temperature

Factors	SS	DF	MS	F	%p
Speed	89.6500	2	44.8250	3.02	17.77
Feed	89.0125	6	14.8354	1	17.65
D.O.C	325.7708	6	54.2951	3.66	64.58
Total	504.433				100.00

It can be seen from the ANOVA for temperature analysis that depth of cut is most significant parameter affecting temperature with 64 % significance. The significance of speed and feed is found poor as compare to depth of cut.

Contour plots are given below to understand relationship between parameters and Temperature.

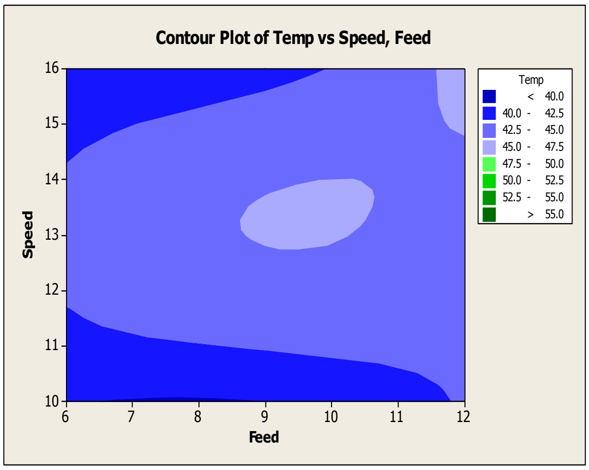

Figure 4.2 Contour plot of Temperature Vs Speed, Feed

From Figure 4.2 it can be seen that temperature is more for feed of 9-10 mm/min and speed of 12-14 m/min region. Higher and lower speed can decrease the temperature.

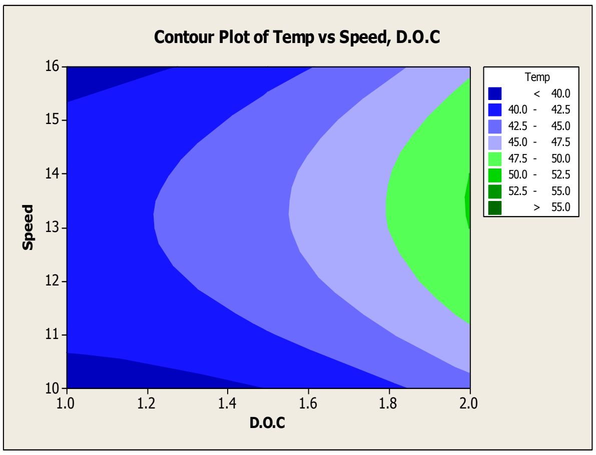

Figure 4.3 Contour plot of Temperature Vs Speed, D.O.C

As seen from Figure 4.3 temperature would be higher for higher depth of cut. For higher and lower speed temperature would be more.

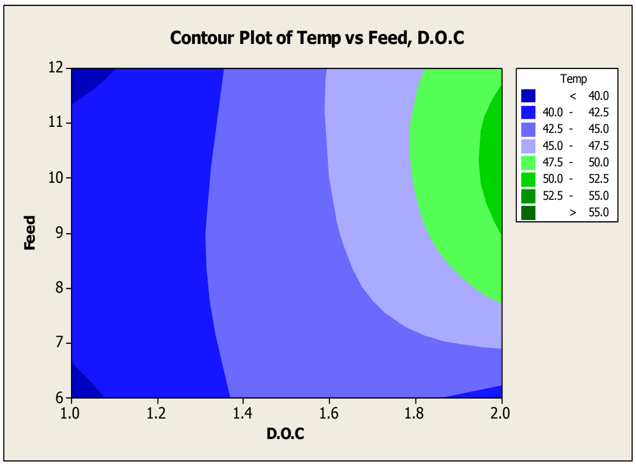

Figure 4.4 Contour plot of Temperature Vs Feed, D.O.C

From Figure 4.4 it is clear that temperature would increase with increase in depth of cut. It can be seen from figure that feed would not affect more to temperature as compare to depth of cut.

5. CONCLUSIONS

Based on experimental observations, graphs are plotted & results are critically discussed. It can be concluded from the results that for particular material different parameters make different relations with response.

The temperature of work piece during machining has higher influence with chosen parameters and could not be overlooked as it affects the properties of the machined surface.

Temperature would be increased with the increase of depth of cut, and it would be increased with increase in feed and speed also.

Depth of cut is the most significant parameter as far as temperature is concerned. Therefore lower depth of cut is desired for minimizing temperature of work piece during machining.

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