Optimization of the Cutting Responses in Boring Operation Using Response Surface Methodology

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***Abstract*— In the present work, an attempt is made to select the combination of optimum cutting parameters which will yield in better surface finish, minimum tool wear and minimum tool temperature. Three parameters mainly cutting speed (V), feed rate (f) and depth of cut (d) are taken as the control factors. EN 31 is used as the job material and Tungsten carbide is used as the tool insert. Response Surface Methodology (RSM) approach is followed to optimize the parameters. This shows that a proper selection of the cutting parameters produces a better surface finish, minimum tool wear and minimum tool temperature. The optimum parameters were obtained using RSM and the confirmation experiment was carried out to validate the optimum parameter settings.**

Keywords*— Optimization, Boring, Tool temperature, Tool wear, Surface roughness, Response surface roughness, Optimal conditions

I. INTRODUCTION

Boring is a process of producing circular internal profiles on a hole made by drilling or another process. It uses single point cutting tool called a boring bar. In boring, the boring bar can be rotated, or the work part can be rotated. Machine tools which rotate the boring bar against a stationary work piece are called boring machines (also boring mills). Boring can be accomplished on a turning machine with a stationary boring bar positioned in the tool post and rotating work piece held in the lathe chuck.

When boring with a rotating tool, size is controlled by changing the radial position of the tool slide, which holds the boring bar, with respect to the spindle axis of rotation. For finishing machining, the boring bar is additionally mounted in an adjustable boring head for more precise control of the bar radial position.

II. LITERATURE REVIEW

A.M.Badadhe, S. Y. Bhave, L. G. Navale [1] took the Four parameters viz. spindle speed, feed, depth of cut and length to diameter (L/D) ratio of boring bar as control factors and selected the combination of optimum cutting parameters for better surface finish. AISI 1041 (EN9) carbon steel was used as the job material which was cut by using standard boring bars of various sizes each having a tungsten carbide inserts of same insert radius. The study showed that the control factors had varying effects on the response variable.

Miroslav, Radovanović [2] showed that depth of cut is the most significant parameter, affecting the cutting force components with contribution of 60.63% for main cutting force and 70.18% for feed force, followed by the feed with contribution of 36.96 for main cutting force and 22.08% for feed force. The cutting speed has smaller effect with contribution of 1.77% for main cutting force and 5.88% for feed forceusing the ANOVA table. **Yiğit Karpat & Tuğrul Özel** [3] introduced aprocedure to formulate and solve optimization problems for multiple and conflicting objectives that may exist in finish hard turning processes using neural network modeling together with dynamic- neighborhood particle swarm optimization technique.The results indicate that the proposed swarm intelligent approach for solving the multi-objective optimization problem with conflicting objectives is both effective and efficient, and can provide intelligence in production planning for multi-parameter turning processes.

GauravVohra, Palwinder Singh, Harsimran Singh [4] studied that in aluminium the optimum value will be achieved when the Spindle Speed is 108.687 and feed rate .1 and depth of cut 1.03535.In this parameter the, finishing was observed to be maximum. Considering the individual parameters, had been found that depth of cut and cutting speed to be the most influencing parameter, followed by the feed rate. **Harsimran Singh Sodhi, DhirajPrakashDhiman, Ramesh Kumar Gupta, Raminder Singh Bhatia** [5] used Taguchi parameter optimization methodology is applied to optimize cutting parameters in boring. The results of analysis showed that feed rate and cutting speeds have present significant contribution on the surface roughness and depth of cut have less significant contribution on the surface roughness. The Best value for the Surface Roughness is at Speed 120 m/min, feed rate 0.10 rev/min and Depth of cut 1.0 mm.

Show-Shyan Lin, Ming-Tsan Chuang, Jeong-Lian Wen, and Yung-KuangYang [6] conducted nine experimental runs based on an orthogonal array of Taguchi method. The surface properties of roughness average and roughness maximum as well as the roundness were selected as the quality targets. The feed rate is identified to be the most influence on the roughness average and roughness maximum, and the cutting speed is the most influential factor to the roundness. It was found that the largest value of the grey relational grade for the cutting speed of 85 m/min, the feed rate of 0.05 mm/rev, and the depth of cutting of 0.6 mm.

From the literature review, it was found that spindle speed , feed and depth of cut were the main parameters that affected the finishing of a product in boring.

III. EXPERIMENTAL SETUP

In statistics, response surface methodology (RSM) explores the relationships between several explanatory variables and one or more response variables. The method was introduced by G. E. P. Box and K. B. Wilson in 1951. The main idea of RSM is to use a sequence of designed experiments to obtain an optimal response. Box and Wilson suggest using a second-degree polynomial model to do this. They acknowledge that this model is only an approximation, but use it because such a model is easy to estimate and apply, even when little is known about the process. The experimental setup is shown in Fig 1.

An easy way to estimate a first-degree polynomial model is to use a factorial experiment or a fractional factorial design. This is sufficient to determine which explanatory variables have an impact on the response variable(s) of interest. Once it is suspected that only significant explanatory variables are left, and then a more complicated design, such as a Box–Behnkendesign can be implemented to estimate a second-degree polynomial model, which is still only an approximation at best. However, the second-degree model can be used to optimize (maximize, minimize, or attain a specific target for).

The initial boring parameters were spindle speed of 600 m/min, feed rate of 0.08 mm/rev and depth of cut of 0.75 mm. These parameters were selected based on the experience from the boring operators and reference. The initial parameters are shown in Table 1.

Figure 1. Experimental setup

TABLE I. GRINDING PARAMETERS AND THEIR LEVELS

Symbols	Controlled parameters	Level 1	Level 2	Level 3
N	Spindle speed (m/min)	400	600*	800
F	Feed Rate (mm/rev)	0.06	0.08*	0.10
d	Depth of cut (mm)	0.5	0.75*	1.0

* : initial parameters

The average surface roughness was calculated using Mitutoyo Surftest SJ 210. The average surface roughness (R_a) value was measured in µm. The sampling length was 8mm. The Raytek Minitemp MT4 infrared thermometer is non-contact with laser sighting was used to measure the temperature at the tool-work interface. The tachometer used is SYSTEM HTM-560. The HTM-560 has a sampling rate of one second. The MM400/800 is a new series of innovative measuring microscopes designed for industrial measurement and image analysis.

IV. EXPERIMENTATION

The total numbers of experiments were selected as nineteen. The sequences of experiments were given by the Design Expert software as shown in Table II. For three factors and three levels, there will be a total of 12 experiments. The number of centre blocks was selected as 7, to increase the efficiency of the optimum parameters.

The experiments were conducted. The experimental design layout after the value of surface roughness, temperature and tool wear entered in the experimental design layout is shown in Table II.

TABLE I
RESPONSE ENTERED IN THE DESIGN LAYOUT

		Factor 1	Factor 2	Factor 3	Response 1	Response 2	Response 3
Std	**Run**	**A:SPEED**	**B:FEED**	**C:DEPTH OF CUT**	**SURFACE ROUGHNESS**	**TOOL TEMPERATURE**	**TOOL WEAR**
		Rpm	**mm**	**mm**	**µm**	**°C**	**mm**
16	1	600	0.08	0.75	1.231	192	0.03
10	2	600	0.1	0.5	1.501	210	0.03
4	3	800	0.1	0.75	3.415	270	0.06
1	4	400	0.06	0.75	3.471	54	0.01
18	5	600	0.08	0.75	1.254	193	0.03
6	6	800	0.08	0.5	2.855	246	0.05
8	7	800	0.08	1	3.208	260	0.05
5	8	400	0.08	0.5	3.211	66	0.01
2	9	800	0.06	0.75	2.315	239	0.04
7	10	400	0.08	1	2.853	78	0.02
17	11	600	0.08	0.75	1.259	194	0.03
11	12	600	0.06	1	1.496	135	0.03
14	13	600	0.08	0.75	1.265	197	0.03
12	14	600	0.1	1	1.866	218	0.04
13	15	600	0.08	0.75	1.268	198	0.03
3	16	400	0.1	0.75	2.319	109	0.02
15	17	600	0.08	0.75	1.265	197	0.03

9	18	600	0.06	0.5	1.852	118	0.03
19	19	600	0.08	0.75	1.245	199	0.03

V. RESULT AND DISCUSSION

The output response is entered in the Design Expert 8 software and the optimization is done. The output response was analysed and model graphs were obtained. Then numerical optimization was done after setting the goal to minimise the surface roughness.

The numerical optimal solution is shown in the Table III.

A. *Effect on Surface Roughness*

1) Effect of Speed and feed on surface roughness

As the depth of cut increases, the value of surface roughness keeps on decreasing and after reaching a particular value, it increases The two interactions between the variables (speed-surface roughness, feed-surface roughness) in the model were form of a curvature and these lines in the contour plot were not parallel straight lines. The response contour plots indicated the maximum, minimum and variation of the cutting response values. In Fig 2, the curvatures were obtained in all the interactions and the maximum values of surface roughness for various combinations of the cutting parameters were studied.

2) Effect of feed and depth of cut on surface roughness

The model obtained was in the form of a curvature. The interactions between the variables (depth of cut-surface roughness, feed-surface roughness) in and these lines in the contour plot were not parallel straight lines. The response contour plots indicated the maximum, minimum and variation of the cutting response values. Fig 3 shows that the curvatures were obtained in all the interactions and the maximum values of surface roughness for various combinations of the cutting parameters were obtained.

B. *Effect on Tool Temperature*

1) Effect of Speed and depth of cut on Tool Temperature

The response contour plots indicated the maximum, minimum and variation of the cutting response values. Fig 4 shows that the curvatures were obtained in all the interactions and the maximum values of tool temperature for various combinations of the cutting parameters were studied.

2) Effect of feed and depth of cut on Tool Temperature

The two interactions between the variables (depth of cut-tool temperature, feed-tool temperature) in the model were form of a curvature and these lines in the contour plot were not parallel straight lines. The response contour plots indicated the maximum, minimum and variation of the cutting response values. Fig 5 shows that the curvatures were obtained in all the interactions and the maximum values of tool temperature for various combinations of the cutting parameters were studied.

TABLE III
Optimum Parameters For Boring Process

PARAMETER	OPTIMUM VALUE
N	517.45 rpm
F	0.06mm/rev
d	0.87 mm

C. *Effect on Tool Wear*

1) Effect of Speed and feed on tool wear

The curvatures obtained are the result of interactions between speed and tool wear and feed and tool wear. The cutting response values are obtained by analysing the various responses of the contour plots. The tool wear for various combinations of the cutting parameters were studied.

2) Effect of feed and depth of cut on tool wear

The response contour plots indicated the maximum, minimum and variation of the cutting response values. Fig 7 show that , the curvatures were obtained in all the interactions and the maximum values of tool wear for various combinations of the cutting parameters were studied. The two interactions between the variables (depth of cut-tool wear, feed-tool wear) in the model were form of a curvature and these lines in the contour plot were not parallel straight lines.

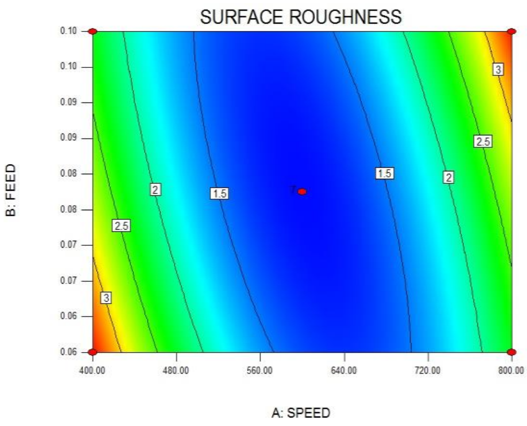

Fig. 2. Effect of speed and feed on surface roughness

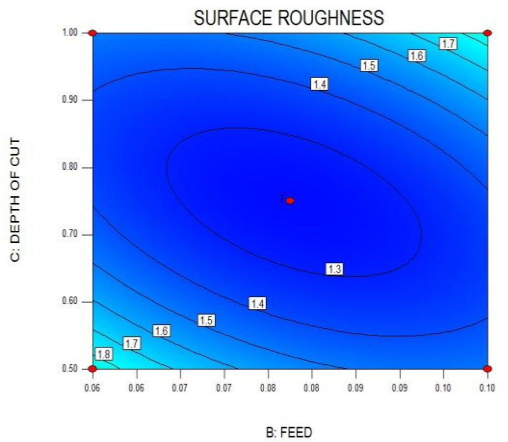

Fig. 3. Effect of feed and depth of cut on surface roughness

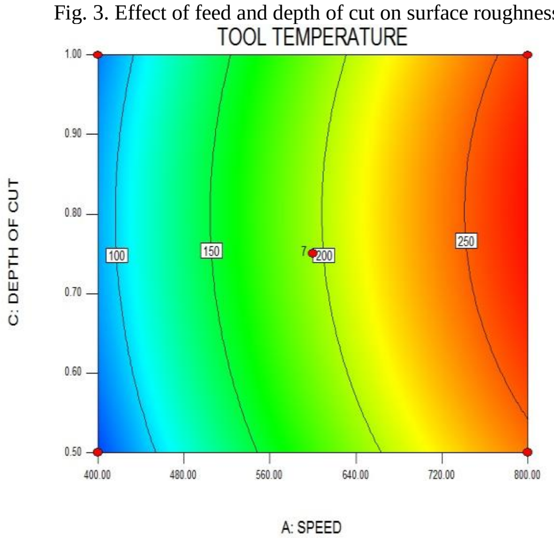

Fig. 4. Effect of Speed and depth of cut on Tool Temperature

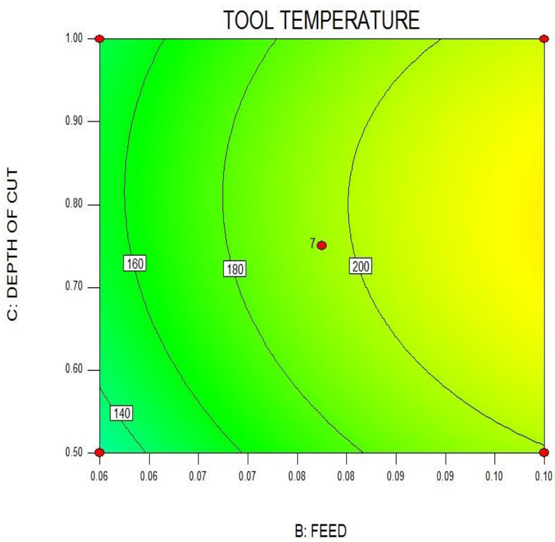

Fig. 5. Effect of feed and depth of cut on Tool Temperature

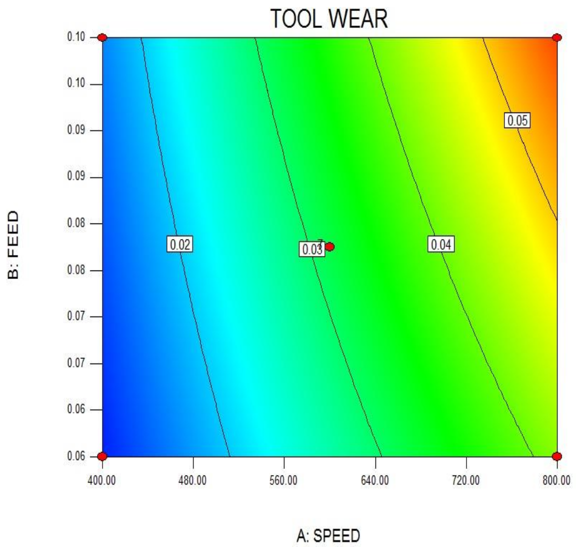

Fig. 6. Effect of speed and feed on tool wear

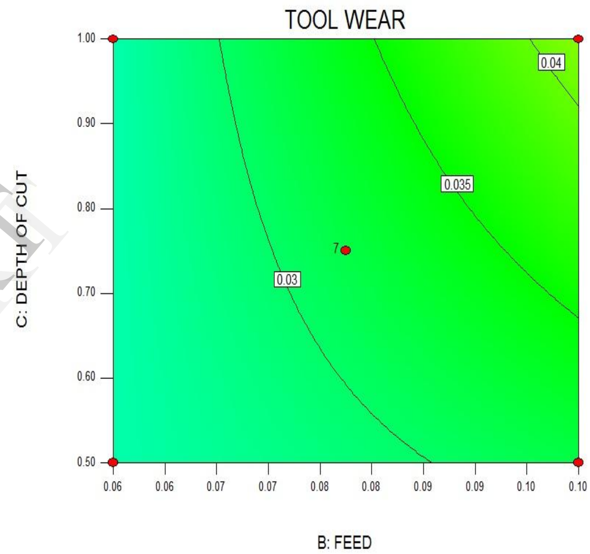

Fig. 7. Effect of feed and depth of cut on tool wear

The optimized solution for surface roughness was obtained to be 1.82862 μm. The surface roughness value first decreases, as the speed increases and then increases dramatically as the speed approaches 800 rpm. This is because as the speed increases, the value of cutting forces also increases. This causes tool vibration, machine vibration and the value of surface roughness increases for high speeds.

The optimized solution for tool temperature was obtained to be 111.594 °C. The tool temperature keeps on increasing as the feed and speed increases. This shows that the tool temperature is directly proportional to feed and speed. The value of tool temperature increases dramatically as the speed approaches 800 rpm as shown in Figure 9.

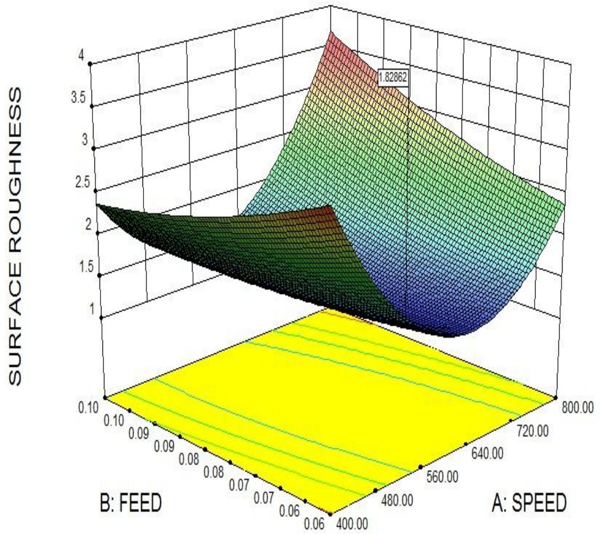

Fig. 8. Surface roughness Vs Feed Vs Speed

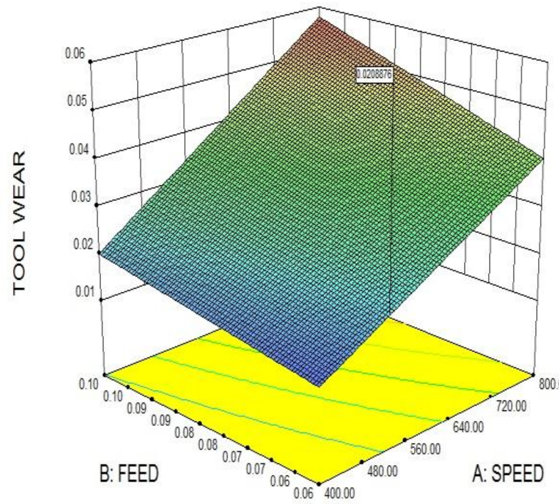

Fig. 10. Tool wear Vs Feed Vs Speed

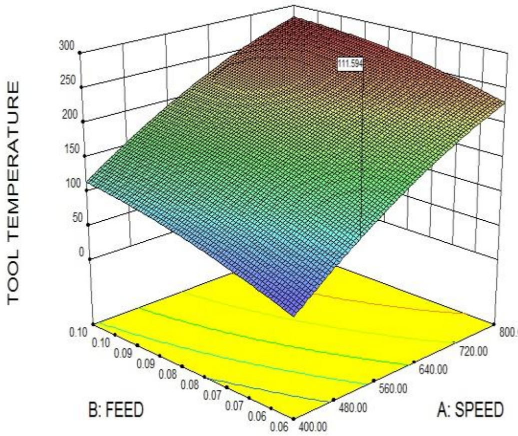

Fig. 9. Tool temperature Vs Feed Vs Speed

The optimized solution for tool wear was obtained to be 0.0208876 mm. The tool temperature keeps on increasing as the feed and speed increases. This shows that the tool wear is directly proportional to feed and speed. The value of tool wear increases dramatically as the speed approaches 800 rpm as shown in Figure 10.

After analyzing the experimental results the optimal parameter values are determined. The optimized process parameter values are Speed=517.45 m/min, Feed=0.06mm/rev and Depth of cut=0.87 mm.

VI. CONCLUSION

In boring operations, high surface roughness values were obtained. Response Surface Methodology was selected to determine the optimal process parameters. Experiments have been conducted based on the design expert software and the results obtained were analyzed. Confirmation experiments were conducted based on optimum process parameter values.

The process parameters for minimizing the surface roughness, tool wear and tool temperature are,

Speed =517.45 rpm.
Feed =0.06 mm/rev.
Depth of cut =0.87 mm.

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