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Factor Optimization of CNC Vertical Machining Center for EN24 Steel using Taguchi's Method

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Abstract—*Taguchi's Method with Design of Experiment greatly reduces number of iterations in process optimization and helps in finding effects of various parameters. We have employed this method in optimizing the spindle speed, feed and depth of cut during milling operation of material EN24 steel on VMC machine with surface roughness and material removal rate as response variables. In the experimentation, we have used 3-level design and L-9 orthogonal array. The milling operations was performed on round bar (Ø100mm) and machining time for each cut was noted. The surface roughness (R_a value) of each cut was measured with help of digital surface roughness tester. The S/N ratio was calculated for surface roughness based on smaller the better approach and for material removal rate based on larger the better approach. The graphs of the effects of control factors is shown using MINITAB15.0 software. The percentage influence of various control factors is also calculated using ANOVA technique. It is noted that depth of cut greatly affects the material removal rate while surface roughness is more affected by spindle speed.*

1. INTRODUCTION

Now-a-days, increasing the productivity and controlling the machining quality of mechanical components has become a main challenge in metal based industry. Milling is one of the most widely used machining process these days. In this era of Industrialization, CNC Vertical Machining Center machines are most widely used for milling of various components. So optimizing the parameters of these machines during milling operation helps in economic manufacturing and improving quality measures like surface finish.

EN24 is medium-carbon low-alloyed steel which is used widely in manufacturing automobile and machine tools parts. EN24 steel has properties like low specific heat and tendency to strain-harden and diffuse between tool and work material which gives rise to certain problems in its machining such as high cutting tool temperatures, large cutting forces, poor surface finish and built-up edge formation. Thus its machining becomes very difficult.

The objective of this experimental investigation is to ascertain the effects of cutting speed, feed rate and depth of cut on Material removal rate and surface roughness in CNC milling (dry machining) of EN24 steel. Taguchi's technique with Design of Experiments has been used to fulfill the objective. L9 orthogonal array used for conducting the experiments.

The main reason behind the use of the designed experiment is to analyze the system completely with the effect of the different important parameters to get the appropriate combination of the working state for improvement of the output of the system. For design of experiment technique, the knowledge of basic mathematics and statistical is required. So, it is easy to use for such engineering and scientific applications.

2. EXPERIMENTATION AND DATA COLLECTION

2.1 Quality characteristic of the experimental setup:

- Quality characteristic: Surface roughness and Material removal rate.
- Work material: EN24 Steel (Fe (94.82%-96.62%),
- C (0.35%-0.45%), Mn (0.45%-0.70%), Si (0.10%-0.35%), Cr (0.90%-1.40%), Ni (1.30%-1.80%),
- Mo (0.20%-0.40%), S (< 0.04%))[16]
- Cutting tool: Carbide end mill cutter of 12 mm diameter.
- Operating Machine: CNC vertical milling machine.
- Testing equipment: Digital surface roughness tester.

2.2 Different Parameters:

In the experiment we will consider the affecting parameter as spindle speed, feed rate and depth of cut and we will check effect of this parameters on the surface roughness.

Table 2.1: Parameters and response variable

Parameters	Response variable
Spindle speed	Surface Roughness
Feed rate	Material Removal rate
Depth of cut	

Fig. 2.1: Milling on VMC-640 manufactured by Jyoti CNC

2.3 Selection of levels for affecting factors:

According to properties of the material which is used in the machining we have decide the level of the affecting parameter for the further experiments. We used three level design for the project.

Table 2.2: Different levels of the affecting control factors

Factor	Levels		
	1	2	3
Spindle Speed(rpm)	1250	1000	1500
Feed Rate(mm/min)	135	120	150
Depth of cut(mm)	0.5	0.2	0.8

2.4 Selection of Orthogonal array

For selection of the orthogonal array first we have to decide the degree of freedom of the given parameters.

Degree of freedom:

- One mean value
- Other two levels for each variable so, degree of freedom = 8
- Total degree of freedom = 9

According to degree of freedom system we will choose the orthogonal array as L9 array for the experiments.

Table 2.3: Orthogonal array

Experiment no.	Control Factor		
	Speed	Depth of cut	Feed rate
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	3
5	2	2	1
6	2	3	2
7	3	1	2
8	3	2	3
9	3	3	1

Table 2.4: Orthogonal array with control factor value

Experiment no.	Control factor		
	Speed	Depth of cut	Feed rate
1	1250	0.5	135
2	1250	0.2	120
3	1250	0.8	150
4	1000	0.5	150
5	1000	0.2	135
6	1000	0.8	120
7	1500	0.5	120
8	1500	0.2	150
9	1500	0.8	135

2.5 Conducted Experiments:

As per the orthogonal array L9 we have conduct the experiments and the result of the experiments is shown in the table given below

Table 2.5: Result of the experiments

Experiment no.	Control factor			Response factor	
	Spindle Speed (Rpm)	Depth of cut (mm)	Feed rate (mm/min)	Material removal rate (mm^3/s)	Surface roughness (µm)
1	1250	0.5	135	11.34768	1.82
2	1250	0.2	120	4.390873	2.481
3	1250	0.8	150	24.26647	2.784
4	1000	0.5	150	13.62465	3.398
5	1000	0.2	135	4.47374	3.224
6	1000	0.8	120	15.53572	2.446
7	1500	0.5	120	10.76183	1.06
8	1500	0.2	150	5.446068	1.988
9	1500	0.8	135	18.7902	1.866

Fig. 2.2: Digital Surface Roughness Tester by Mitutoyo

2.6: Examining the data:

Table 2.6: Calculated S/N Ratio

Experiment No.	Material Removal Rate (mm^3/s)	Surface roughness (µm)
1	21.09814	-5.20143
2	12.85102	-7.89254

3	27.70013	-8.89338
4	22.68651	-10.6245
5	13.01343	-10.1679
6	23.82663	-7.76913
7	20.63772	-0.50612
8	14.72166	-5.96833
9	25.47863	-5.41823

Table 2.7: S/N ratio for material removal rate

Level	Spindle speed (rpm)	Depth of Cut (mm)	Feed rate (mm/min)
1	20.549763	21.47412	19.8634
2	19.8421876	13.5287	19.10512
3	20.2793368	25.66846	21.70277

Table 2.8: S/N ratio for Surface roughness

Level	Spindle speed (rpm)	Depth of Cut (mm)	Feed rate (mm/min)
1	-7.3291159	-5.44	-6.92919
2	-9.5204991	-8.0096	-5.38926
3	-3.9642259	-8.49539	-7.36025

Table 2.9: Level weight for the material removal rate

Level	Spindle speed (rpm)	Depth of cut (mm)	Feed rate (mm/min)
1	1	0.836596	0.915247
2	0.9655676	0.527055	0.880308
3	0.98684031	1	1

Table 2.10: Level weight for the surface roughness

Level	Spindle Speed (rpm)	Depth of cut (mm)	Feed rate (mm/min)
1	0.54088733	1	0.777762
2	0.41638846	0.679686	1
3	1	0.739649	0.634374

Table 2.11: Total weight of the control factors

Level	Spindle speed (rpm)	Depth of cut (mm)	Feed rate (mm/min.)
1	0.77044366	**0.918298**	0.846505
2	0.69097803	0.603371	**0.940154**
3	**0.99342016**	0.869825	0.8171847

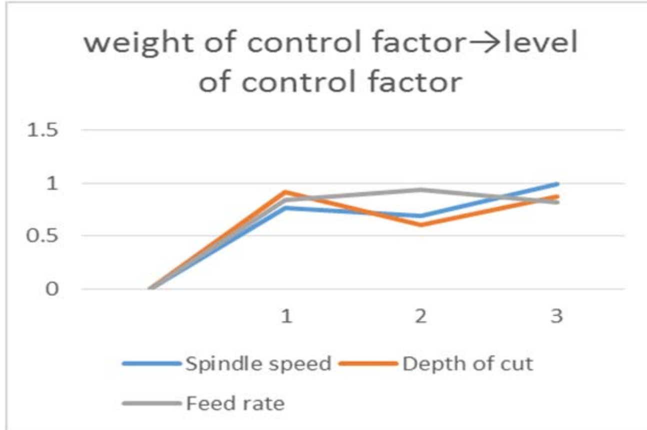

Fig. 2.3: Graph of weight of control factor → level of control variable)

From the experimentation data and the results we got the optimized state as below:

Table 2.12: Result

Control variable	Level
Spindle speed (rpm)	1500
Depth of cut (mm)	0.2
Feed rate (mm/min.)	135

3. CONCLUSIONS

- From the experimental results, following conclusions can be drawn:
- Independently, spindle speed is most significant parameter affecting the surface finish while depth of cut is most significant in case of Material removal rate.
- Considering the combined effect of all the parameters for optimum state to improve surface finish and material removal rate, spindle speed is the most influencing parameter followed by feed rate and then depth of cut.
- The results of this experiment will be useful in reducing tool temperature, tool vibrations, power consumption, thus resulting in economic and good quality manufacturing.

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