Research Article

OPTIMIZATION OF CUTTING PARAMETERS OF END MILLING ON VMC USING TAGUCHI METHOD

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ABSTRACT

In this paper, the milling of OHNS steel material using End milling with a high speed steel tool material by using Taguchi methodology has been reported. The Taguchi method is used to formulate the experimental layout, to analyse the effect of each parameter on the machining characteristics, and to predict the optimal choice for each end milling parameter such as Speed, Feed, Depth of cut. It is found that these parameters have a significant influence on machining characteristic such as material removal rate (MRR), surface roughness (Ra, Rq and Rz), parallelism. The analysis using Taguchi method reveals that, in general the depth of cut significantly affects the MRR and speed significantly affects the surface roughness.

KEYWORDS: End milling, Taguchi method, OHNS steel, material removal rate, surface roughness (Ra, Rq and Rz), parallelism.

INTRODUCTION:

In case of end milling operation, metal is usually removed from a work piece by a single or multiple point cutting tool. For the efficient use of the machine tool it is important to find the optimum cutting parameters before a part is put into production. End mills are used in tracer controlled profile milling operations. They are employed for making deep grooves in base parts, profile recesses, steps, etc. End mills can be used on horizontal milling machine, but it is better to use them on vertical milling machine. Their diameter varies from about 3mm to 50mm. End mills are those tools which have cutting teeth at one end, as well as on the sides. The words end mill are generally used to refer to flat bottomed cutters, but also include rounded cutters (referred to as ball nosed) and bull nose cutters. They are usually made from high speed steel (HSS) or carbide, and have one or more flutes. They are the most common tool used in a vertical mill. Schematic diagram of End milling operation is shown in Figure 1.

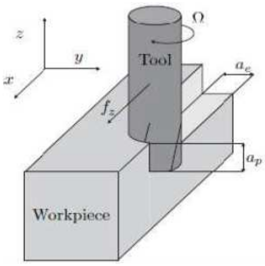

Figure 1 End Milling Operation

where,

1. a_e is radial depth of cut in mm
2. f_z is feed per tooth in mm/tooth
3. a_p is axial depth of cut in mm.

Table 1: Chemical composition of OHNS Steel.

Sr. No.	Element	%
01	Carbon	0.9 to 1.3
02	Manganese	1
03	Chromium	0.5
04	Tungsten	0.4 to 0.8
05	Nickel	0.5
06	Iron	Balance

DESIGN OF EXPERIMENTS:

Taguchi Method:

Taguchi methods are the most recent additions to the toolkit of design, process and manufacturing engineers, and quality assurance experts. In contrast to statistical process control, which attempts to control the factors that adversely affect the quality of production, Taguchi methods focus on design the development of superior performance designs (of products and manufacturing processes) to deliver quality.

An experimental design scheme of statistical experiments that uses orthogonal arrays however entails the following considerations and consequences:

- The orthogonal array leads only to a main effect design. Use of an orthogonal array forces the investigator to assume that the response one observe can be approximated by an additive function, separable into the effects of the individual (main) control factors under study. One assumes no other effects, in particular no interactions, to be present. A verification experiment can later verify whether this approximation is satisfactory and a valid one.
- The columns of the orthogonal arrays are pair wise orthogonal. In every pair of columns, all combinations of the levels of each (independent) factor under study occur and they do so equal number of times.
- It follows from No. 2 that the main effect estimates of all factors and their associated sum of squares are independent under the assumption of normality and equality of observation variance. Hence the significance test (ANOVA) for these factors are independent.
- When orthogonal array guides the experiments, one computes the main factor effect. These computed effect may be then used to predict the response for any combination of factor treatments, because one assumes that these effects are separable and additive. The variance of the prediction error (caused by factors not controlled in the experiments and the exclusion of interactions) is the same for all such treatment combinations.
- Factors which are studied may be discrete or continuous. For continuous factors it is possible to break down main effects of three level factors into linear and quadratic terms. A non-linear effect may sometimes be useful in fine tuning and improving the initial design.
- In the initial stages of optimization, one may limit the investigation to the study of main effect. Later on, it is possible to run larger orthogonally designed experiments to study interaction effects also, if necessary.

Signal to Noise Ratio:

Classical experimental design methods are too complex and not easy to use. Furthermore, a large number of experiments have to be carried out as the number of the process parameters increases. To solve this important task, the Taguchi method uses a special design of orthogonal array to study the entire parameter space with only a small number of experiments. The experimental results are then transformed into a signal-to-noise (S/N) ratio. The S/N ratio can be used to measure the deviation of the performance characteristics from the desired values. The categories of performance characteristics in the analysis of the S/N ratio depend upon output parameters to be controlled. We have selected two categories which are as follows.

- The lower-the-better for surface roughness (Ra, Rq and Rz) , parallelism
- The higher-the-better for MRR

Regardless of the category of the performance characteristic, a larger S/N ratio corresponds to better performance characteristic. Therefore, the optimal level of the process parameters is the level with the highest S/N ratio.

Design of Experiment for End Milling of OHNS Steel Material:

The design of experiment (D.O.E.) chosen for the End Milling of OHNS Steel Material was a Taguchi L16 orthogonal array, by carrying out a total number of 16 experiments along with 5 verification experiments (optional).

L16 Orthogonal Array:

In L16 (4^3) array 16 rows represent the 16 experiment to be conducted with 3 columns at, 4 levels of the corresponding factor. The matrix form of these arrays is shown in Table 2, where 1, 2, 3, 4 in the table represents the level of each parameters.

Input Factors:-

1) Speed
2) Feed
3) Depth of cut

Design of experiment (L16) is shown in Table 2.

Table 2 Design of Experiment (L16)

Exp. No.	Factor 1 Speed	Factor 2 Feed	Factor 3 Depth of cut
E1	1	1	1
E2	1	2	2
E3	1	3	3
E4	1	4	4
E5	2	1	2
E6	2	2	1
E7	2	3	4
E8	2	4	3
E9	3	1	3
E10	3	2	4
E11	3	3	1
E12	3	4	2
E13	4	1	4
E14	4	2	3
E15	4	3	2
E16	4	4	1

Responses measured:

1) Material Removal Rate (MRR)
2) Surface Roughness (Ra, Rq and Rz)
3) Parallelism

Table 3 Level values of Input factors

Sr.No	Factors	Levels			
		1	2	3	4
1	Speed (RPM)	2700	2900	3100	3300
2	Feed	1000	1150	1300	1450
3	Depth of Cut (mm)	0.10	0.13	0.16	0.20

Table 4 Taguchi L16 Orthogonal array Design Matrix

Exp. No.	Speed(RPM)	Feed (mm/min)	Depth of cut (mm)
E1	2700	1000	0.10
E2	2700	1150	0.13
E3	2700	1300	0.16
E4	2700	1450	0.20
E5	2900	1000	0.13
E6	2900	1150	0.10
E7	2900	1300	0.20
E8	2900	1450	0.16
E9	3100	1000	0.16
E10	3100	1150	0.20
E11	3100	1300	0.10
E12	3100	1450	0.13
E13	3300	1000	0.20
E14	3300	1150	0.16
E15	3300	1300	0.13
E16	3300	1450	0.10

Table 5 Experimental Results based on Taguchi L16 Orthogonal Array

Exp. No.	MRR (mm^3/min)	Ra (μm)	Rq (μm)	Rz (μm)	Parallelism (mm)
E1	0.155	1.805	2.155	8.921	0.099
E2	0.149	2.689	3.206	12.834	0.025
E3	0.331	1.743	2.438	14.042	0.021
E4	0.477	2.328	2.850	10.658	0.021
E5	0.184	1.733	2.043	7.715	0.109
E6	0.149	1.556	1.830	7.755	0.100
E7	0.436	1.777	2.092	8.970	0.007
E8	0.415	1.91	2.171	9.176	0.005
E9	0.254	2.543	2.924	13.395	0.031
E10	0.671	1.714	2.120	10.791	0.233
E11	0.210	1.328	1.676	7.428	0.026
E12	0.567	1.887	2.204	7.403	0.018
E13	0.311	1.793	2.215	8.650	0.204
E14	0.273	1.049	1.263	6.014	0.024
E15	0.314	1.058	1.245	5.732	0.015
E16	0.303	1.082	1.311	6.393	0.017

Table 6 Calculation of Signal to Noise ratio for Various Response Factors

Exp. No.	S/N ratio of MRR	S/N ratio of Ra	S/N ratio of Rq	S/N ratio of Rz	S/N ratio of Paralle -lism
E1	-16.193	-5.130	-6.669	-19.008	20.087
E2	-16.536	-8.592	-10.119	-22.167	32.041
E3	-9.603	-4.826	-7.741	-22.949	33.556
E4	-6.430	-7.340	-9.097	-20.554	33.556
E5	-14.704	-4.776	-6.205	-17.747	19.251
E6	-16.536	-3.840	-5.249	-17.792	20.000
E7	-7.210	-4.994	-6.411	-19.056	43.098
E8	-7.639	-5.062	-6.733	-19.253	46.021
E9	-11.903	-8.107	-9.320	-22.539	30.173
E10	-3.466	-4.680	-6.527	-20.661	12.653
E11	-13.556	-2.464	-4.485	-17.417	31.701
E12	-4.928	-5.515	-6.864	-17.388	34.895
E13	-10.145	-5.072	-6.907	-18.740	13.807
E14	-11.277	-0.416	-2.028	-15.583	32.396
E15	-10.061	-0.490	-1.903	-15.166	36.478
E16	-10.371	-0.685	-2.352	-18.327	35.391

Effect of Input Parameters on various response factors

Table 7 The response table for S/N Ratios for MRR

Level	Speed	Feed	Depth of Cut
1	-12.191	-13.236	-14.164
2	-11.522	-11.954	-11.557
3	-8.463	-10.108	-10.106
4	-10.464	-7.342	-6.813
Δ	3.728	5.894	7.351
Rank	**3**	**2**	**1**

Table 8 Analysis of Variance for MRR

Sources	D.O.F.	Sum of squares	Mean Square	% Contribution
Speed	3	16.792	5.597	12.17
Feed	3	47.441	15.814	34.37
Depth of Cut	3	73.783	24.594	53.46
Total	9	138.016		

From Table 7 and Table 8 it is observed that depth of cut has the maximum effect on material removal rate.

Table 9 The response table for S/N Ratios for Ra

Level	Speed	Feed	Depth of Cut
1	-6.472	-5.771	-3.030
2	-4.668	-4.382	-4.843
3	-5.192	-3.193	-4.603
4	-1.665	-4.650	-5.521
Δ	4.807	2.578	2.491
Rank	**1**	**2**	**3**

Table 10: Analysis of Variance for Ra

Sources	D.O.F.	Sum of squares	Mean Square	% Contribution
Speed	3	39.076	13.025	69.54
Feed	3	6.723	2.241	11.96
Depth of Cut	3	10.392	3.464	18.50
Total	9	56.191		

From Table 9 and Table 10 it is observed that speed has the maximum effect on surface roughness Ra.

Table 11: The response table for S/N Ratios for Rq

Level	Speed	Feed	Depth of Cut
1	-8.406	-7.275	-4.689
2	-6.150	-5.981	-6.273
3	-6.799	-5.135	-6.455
4	-3.298	-6.262	-7.236
δ	5.108	2.14	2.547
Rank	**1**	**3**	**2**

Table 12 Analysis of Variance for Rq

Sources	D.O.F.	Sum of squares	Mean Square	% Contribution
Speed	3	43.859	14.620	75.38
Feed	3	4.686	1.562	8.05
Depth of Cut	3	9.639	3.213	16.57
Total	9	58.185		

From Table 11and Table 12 it is observed that Speed has the maximum effect on surface roughness Rq.

Table 13 The response table for S/N Ratios for Rz

Level	Speed	Feed	Depth of Cut
1	-21.169	-19.509	-18.136
2	-18.462	-19.051	-18.117
3	-19.501	-18.647	-20.081
4	-16.401	-18.327	-19.753
δ	4.768	1.182	1.964
Rank	**1**	**3**	**2**

Table 14: Analysis of Variance for Rz

Sources	D.O.F.	Sum of squares	Mean Square	% Contribution
Speed	3	40.751	13.584	82.82
Feed	3	1.873	0.624	3.81
Depth of Cut	3	6.580	2.193	13.37
Total	9	49.204		

From table No: 13and 14 it is observed that Speed has the maximum effect on surface roughness Rz.

Table 15 The response table for S/N Ratios for Parallelism

Level	Speed	Feed	Depth of Cut
1	29.810	20.830	26.795
2	32.093	24.272	30.666
3	27.355	36.208	35.536
4	29.518	37.465	25.778
Δ	4.738	16.635	9.758
Rank	**3**	**1**	**2**

Table 16 Analysis of Variance for Parallelism

Sources	D.O.F.	Sum of squares	Mean Square	% Contribution
Speed	3	32.425	10.808	5.40
Feed	3	432.619	144.206	72.10
Depth of Cut	3	134.954	44.985	22.50
Total	9	599.998		

From Table 15and Table 16 it is observed that Feed has the maximum effect on Parallelism.

Experimental Verification:

After performing the statistical analysis on the experimental data, it has been observed that there is one particular level for each factor for which the responses are either maximum (in case of MRR) or minimum (in case of Surface roughness and Parallelism). The signal to noise ratio (S/N ratio) of each responses corresponding to each factor level also has a maximum and a minimum value. So for finding the optimum parameter setting for each response factors, the additive model of Taguchi method is used. S/N ratio is calculated based on the formula containing negative of logarithmic value, which is a monotonic decreasing function. So S/N ratio should be always kept at maximum value. Therefore in finding the optimum parameter setting, the levels of input factors are chosen in such a way that the S/N ratios for those levels have maximum values (for each input factor). There are five optimum parameter settings corresponding to the five response factors. The combination of input factor levels, for which optimum settings will be obtained, is given in Table N0.17.

Table 17: Optimal Parameter settings of input factors

Physical Requirement	Speed (Rpm)	Feed (mm/min)	Depth of Cut (mm)
Maximum MRR	3100	1450	0.2
Minimum Ra	3300	1300	0.1
Minimum Rq	3300	1300	0.1
Minimum Rz	3300	1450	0.13
Parallelism	2900	1450	0.16

Using these, three optimum parameters (Speed, Feed and Depth of cut) settings, five verification experiments has been carried out and the experimental results are shown in Table 18.

Table 18 Experimental results

Verification Experiment No	Verification Experiment for	Experimental Value	Predicted Value
1	Maximum MRR	0.486	0.565
2	Minimum Ra	1.04	1.12
3	Minimum Rq	1.376	1.339
4	Minimum Rz	6.537	6.069
5	Minimum Parallelism	0.008	0.006

RESULTS AND DISCUSSION:

Effect of input factors on Material removal rate

From the graph, it is observed that increase in speed up to 3100 RPM causes higher MRR, but after that it drastically reduces. The feed and depth of cut has significant effect on MRR as MRR goes on increasing with increasing feed and depth of cut. Hence S/N ratio of MRR has mainly depended upon feed and depth of cut.

Effect of input factors on Surface Roughness Ra

From the graph, it is observed that if speed increases Ra is also increases. If feed up to 1300 mm/min causes Ra increases but beyond that it will decreases. And depth of cut has significant influence on Ra value, as depth of cut increases Ra decreases except for range 0.13 to 0.16.

Effect of input factors on Surface Roughness Rq

From the graph, it is observed that increase in speed up to 2900 RPM causes higher Rq, but from 2900 to 3100 rpm Rq decreases again beyond 3100 rpm Rq increases. Feed upto 1300 mm/min Rq increases but beyond that it will decreases. Depth of cut increases Rq will decreases.

Effect of input factors on Surface Roughness Rz

From the graph it is observed that If feed increases value of Rz increases.

Effect of input factors on Parallelism:

From the graph it is observed that If feed increases value of Parallelism increases.

CONCLUSION:-

In end milling of Oil Hardened Non Shrinking Steel (OHNS), the conclusions are made drawn using the experimental observations :-

- The response parameter material removal rate (MRR) mostly affected by depth of cut (d). The effect of feed (F) on MRR is less. The effect of speed (S) on MRR is least as compared with depth of cut (d) and feed (F).
- The input parameter speed (S) affects roughness value Ra mostly. Other input parameters have less impact Ra.
- Alike, roughness value Ra, speed (S) has major effect on roughness value Rq. Input parameters feed (F), depth of cut (d) have less effect on roughness value Rq.
- Speed (S) affects mainly to roughness value Rz. Input parameters feed (F), depth of cut (d) have less effect on roughness value Rz.
- The input parameter feed (F) affects greatly to parallelism. The effect of depth of cut (d) on parallelism is less. Speed (S) affects least to parallelism.
- In Taguchi L16 orthogonal matrix experiment, no interactions between the input factors are considered. But some interaction effect may be present during the experiment. This may result in some observations which do not go with the theoretical belief.
- As the material is OHNS Steel, this can be used for making pressurized dies, punches, tools, etc.

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