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Optimization of Machining Parameters on End Milling of EN 8 Back Shaft for Power Press

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Abstract
Most of the industries carry out various machining processes which are the heart of any industry. The processes are getting advanced day by day in order to achieve goal of efficiency. The paper states about one of the processes namely end milling, and experimentally investigates the effect of input parameters on material removal rate and surface roughness for key way cut on particular back shaft. Design of experiment was carried out by Taguchi method using Minitab software. Signal to noise ratio is applied to find optimum process parameters for TMC end milling. Experiment is carried out on EN 8 material of back shaft by end mill. The end mill is solid carbide material cutting tool having four flutes of 8 mm diameter, shank length 30 mm and cutter length 35 mm, used for experiments on a turning milling centre. A L_{25} orthogonal array and analysis of variance are applied to study the performance characteristic of machining parameters (Cutting Speed, Feed Rate, and Depth of Cut) with considering of higher MRR by maintain surface roughness have been identified. Result obtained by Taguchi method and signal-to-noise ratio match closely by analysis of variance. Regression equation is formulated for estimating predicated value of MRR and surface roughness.

***Keywords:** End milling, milling, TMC, machining parameters*

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INTRODUCTION

The manufacturing industries are facing a great challenge to achieve high quality, good surface finish and high material removal rate with a view to economize in machining. End milling is widely used in a variety of manufacturing industries including the aerospace and automotive sectors, where quality is an important factor in the production of slots, pockets, and precision moulds. In end milling operation back shaft for the power press material removal rate determines the economics of machining and rate or production. In setting the machining parameters, the main goal is to maximise MRR and maintain surface roughness for key way cutting.

In end milling operation on particular back shaft for the power press material removal rate determines the economics of machining and rate or production.

Goal of the modern industries is to manufacture low cost, high quality product in short time. In end milling, to achieve high cutting performance, selection of optimum parameters is determined by the operator’s experience, knowledge or the design data book.

Taguchi method is one of the design of experiment (DOE) methods that are frequently being used for optimization due to saving of cost, time and material. The Taguchi’s dynamic experiments are simple, systematic and efficient method to determine optimum or near optimum setting of machining parameters.

In this study we use Taguchi method to find optimal process variables to achieve minimum variation from targeted value in the milling of EN 8 material by solid carbide cutting tool. Signal to noise ratio was used to analyse the experimental results as well as most effecting parameters to MRR and surface roughness. Regression equations are formulated for estimating predicated value of MRR and surface roughness.

LITERATURE REVIEW

Literature review is an important part of any review or research paper for understanding:

1. The important aspects of work;
2. A data source that work used; and
3. Ideas for further consideration, etc.

End milling process is generally used to manufacture key ways on component according to the component used in machinery. Various researches have been carried out on end milling process and explained various types of experimental and mathematical techniques.

Parashar *et al.* researched on end milling process on a vertical milling machine SV-2E, considering machining parameters optimization in order to improve surface roughness and MRR by using Taguchi method of DOE [1]. Thakore researched on CNC end milling process parameters for aluminium 6061 alloy using carbide tool material by DOE. The paper concludes that by using DOE, surface roughness and MRR are mainly affected by the processing parameters like cutting speed, feed rate and depth of cut [2]. Sahare *et al*. researched on experimental investigation of end milling operation on Al2024. The research paper work concludes that by using DOE, surface roughness and material removal rate are manly affected by the process parameters of cutting speed, feed rate and depth of cut [3]. Vardhan *et al.* researched on optimization of parameters in CNC milling of P20 steel using RSM and Taguchi method. The paper work analyzes the optimum cutting condition to get lower surface roughness and higher MRR using RSM and Taguchi method [4].

Mozammelmia researched on end milling parameters under through-tool cryogenic cooling condition and dealt with quality characteristics such as cutting force, surface roughness and specific cutting energy in milling of hardened steel by use of mathematical modeling and optimization by using RSM. Full factorial based DOE was also used which focused on input variables cutting speed, feed rate [5]. Wojciechoeski *et al.* researched on optimization of machining parameters during ball end milling of hardened steel with various surface inclinations. The paper work presents the measurement of cutting force with variable input parameters as well as calculation of process efficiency for surface inclination [6]. Masmiati *et al*. researched on end milling of S50C medium carbon steel for minimum residual stress cutting force and surface roughness. Thermal and mechanical loading similarly affect the behavior of residual stresses. Therefore, this research focused on effect of milling mode and DOC respectively on the output parameters using mathematical modeling and RSM techniques [7]. Patil and Hussain researched on optimization of machining parameters to improve surface quality. The paper work concludes that radial cutting depth and the interaction between radial cutting depth and axial cutting depth lead to the minimization of surface roughness [8]. Vyboishchik researched on the influence of dynamical parameters on surface quality during ball end milling. The paper work concludes that the response time, included angle, machining time, and cutting force affect surface quality [9]. Costa *et al.* researched on a normal boundary intersection with multivariate mean square error approach for dry end milling process optimization of the AISI 1045 steel. The research paper works concludes that dry machining techniques can be applied successfully without machining [10]. Durkbasa *et al*. researched on optimization of end milling parameters and determination of the effect of edge profile for high surface quality of AISI H 13 steel by using precise and fast measurement. The paper researches of end milling of S50C medium carbon steel and concludes that combination of minimum residual stress, cutting force and surface roughness is obtained during down milling with high spindle speed, intermediate feed rate and low depth of cut [11]. Holkar *et al*. researched on optimization of end milling machining parameters of AISI 321 stainless steel using Taguchi method. The paper work concludes that the optimal parameters for end milling AISI 321TO reduce surface roughness [12]. Rahman *et al.* researched on effects on vibration and surface roughness in high speed micro end-milling of Inconel 718 with minimum quantity of lubrication. The purpose of this paper was to investigate vibration and average surface roughness, Ra of Inconel 718 in micro end-milling and the results were analyzed using ANOVA [13]. Zhang *et al.* researched on optimization of process parameters for minimum energy consumption based on cutting specific energy consumption. The paper provided an efficient solution to reduce the impact of the environment caused by energy consumption and to realize the sustainable manufacturing [14]. Vopat *et al*. researched on influence of different types of copy milling on the surface roughness and tool life of end mills. The research focused on different tool life of samples according to type of copy milling. Tool life of sample for down-copying is longer than for up copying. Cutting tools in up copying showed lower values of surface roughness [15]. Kuram *et al.* researched on optimization of cutting fluid and cutting parameters during end milling by using D-optimal design of experiments. The paper focused on effect of the milling parameters and the cutting fluid types on the milling performance. Most appropriate cutting fluid was selected in accordance with energy, tool life and surface roughness [16]. Lakshmi *et al*. researched on modelling and optimization of process parameters during end milling of hardened steel. This paper presents an experimental investigation on surface finish and material removal rate during the prediction model and optimizes cutting parameters using RSM [17].

METHODOLOGY

For optimization of machining parameters of end milling, various methods of optimization are carried out, namely mathematical modelling, predictive and experimental method. The practical work for optimization has been carried out using DOE.

The end milling operation was done using KT350 Turning Milling Centre (TMC) for end milling process. The back shaft was placed between head stock and tailstock. The back shaft was fixed between centre and tool travel in Z axis for key way cut on back shaft. The Taguchi methodology is carried out using MINITAB 2016 forming the table of Taguchi array. Signal to noise ratio is applied to find significant parameters most influenced on optimum parameters.

MATERIAL AND EXPERIMENTAL

The experimental work is carried out on back shaft of EN 8 material. EN 8 material is medium carbon steel material generally used for power transmission component like shaft, counter shaft, crank shaft, etc. The chemical composition of EN 8 material is shown in Table 1.

Table 1: *Chemical Composition of EN 8.*

Elements	(C)	(Si)	(Mn)	(S)	(P)
Content (%)	0.35–0.45	0.05–0.35	0.60–1	0.015–0.6	0.015–0.06

Back shaft used in power press is shown in Figure 1.

The key way cut is done using end mill of solid carbide material and observe the material removal rate and surface roughness and time count for key way cut on back shaft. According to Taguchi optimization technique, five levels and three factors are selected as shown in Table 2.

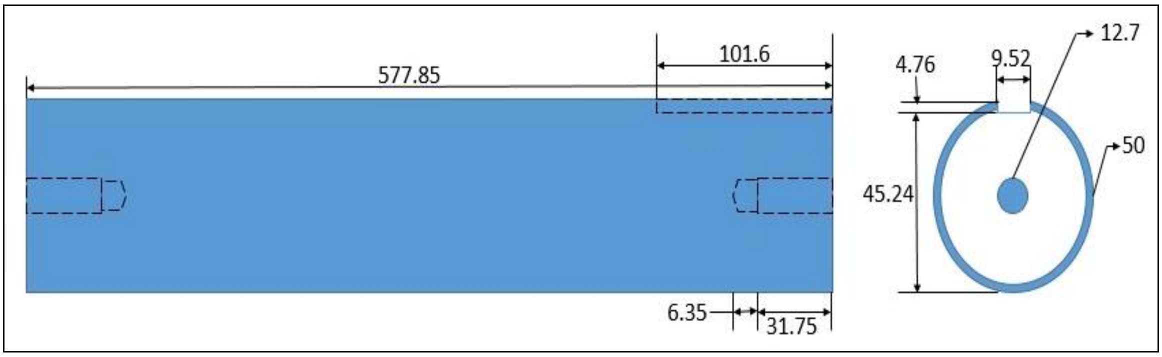

Fig. 1: *Back Shaft.*

EXPERIMENTAL WORK

The experimental work was carried out on KT350 CNC Turning Milling Centre boring machine. The main goal was to find out the optimized parameters for material removal rate and surface roughness. The Taguchi method gives 25 experimental trials for the three factors and five levels, thus experiment was carried out.

Table 2: *End Milling Parameters and Levels.*

Factors	**Units**	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Cutting Speed	m/min.	50	62	74	86	98
Feed Rate	mm/tooth	0.050	0.087	0.124	0.161	0.198
Depth of Cut	mm	0.200	0.275	0.350	0.425	0.500

Table 3: *Experimental Table.*

Practical No.	**Cutting Speed (m/min)**	**Feed Rate (mm/tooth)**	**DOC (mm)**	**Time Count (min)**	**MRR (mm^3/min)**	**Surface Roughness (µm)**
1.	50	0.050	0.200	26.28	175.28	4.9
2.	62	0.087	0.200	12.58	366.17	4.85
3.	74	0.124	0.200	7.58	607.71	4.42
4.	86	0.161	0.200	5.2	886.85	4.28
5.	98	0.198	0.200	3.87	1190.29	4.12
6.	62	0.050	0.275	15.5	297.19	5.02
7.	74	0.087	0.275	7.6	606.11	4.32
8.	86	0.124	0.275	4.77	965.71	5.60
9.	98	0.161	0.275	3.38	1362.85	4.62
10.	50	0.198	0.275	5	921.29	7.61
11.	74	0.050	0.350	9	511.83	4.03
12.	86	0.087	0.350	5	921.29	4.10
13.	98	0.124	0.350	3	1535.48	4.77
14.	50	0.161	0.350	5.3	869.14	7.54
15.	62	0.198	0.350	2.93	1572.16	7.33
16.	86	0.050	0.425	7.52	612.56	4.88
17.	98	0.087	0.425	3.78	1218.63	4.24
18.	50	0.124	0.425	5.73	803.92	7.27
19.	62	0.161	0.425	3.33	1383.32	5.98
20.	74	0.198	0.425	2.45	1880.18	5.88
21.	98	0.050	0.500	6.48	710.87	3.86
22.	50	0.087	0.500	8	575.81	7.88
23.	62	0.124	0.500	4.53	1016.87	6.24
24.	74	0.161	0.500	3	1535.48	6.95
25.	86	0.198	0.500	2	2303.22	7.01
Existing	**70**	**0.060**	**0.350**	**10.77**	**427.71**	**5.64**
Optimum	**98**	**0.124**	**0.350**	**7.52**	**1535.48**	**4.77**
Maximum MRR	**86**	**0.198**	**0.500**	**2**	**2303.22**	**7.01**
Minimum Ra	**98**	**0.050**	**0.500**	**6.48**	**710.87**	**3.86**

OUTPUT RESULTS OF DIFFERENT PARAMETERS

Existing Material Removal Rate Formulae

$$\text{MRR} = \frac{\text{Volume of Material Removed}}{\text{Time Required for Removing Material}} (\text{mm}^3/\text{min.})$$

$$= \frac{\text{Length} * \text{Width} * \text{Depth}}{\text{Time Required for Removing Material}} (\text{mm}^3/\text{min}).$$

$$= \frac{101.6 * 9.525 * 4.76}{10.77} (\text{mm}^3/\text{min.})$$

$$=427.71 (\text{mm}^3/\text{min.})$$

Material removal rate was calculated by MRR equation like volume of material removed from key way divided by time required for removing material.

Existing Surface Roughness

$$\text{Surface Roughness} = \frac{\text{Sum of Three Reading of Surface Roughness}}{\text{Three}} (\mu\text{m})$$

$$= \frac{6.26+4.20+6.45}{3} (\mu\text{m})$$

$$=5.64\ (\mu\text{m}).$$

Surface roughness was measured by Mitutoyo surface roughness tester SJ210. Readings were taken by average reading of three readings on different places of key way.

ANALYSIS

Analysis for Material Removal Rate of EN8 Material

Taguchi Analysis for MRR

Figure 2 shows main effect plot for SN ratios for MRR vs. all input factors. Since it is always desirable to maximize the MRR, 'larger is better' option is selected. From the above graph, it can be seen that highest MRR is achieved at cutting speed of 98 m/sec, depth of cut of 0.198 mm and feed rate of 0.500 mm/tooth.

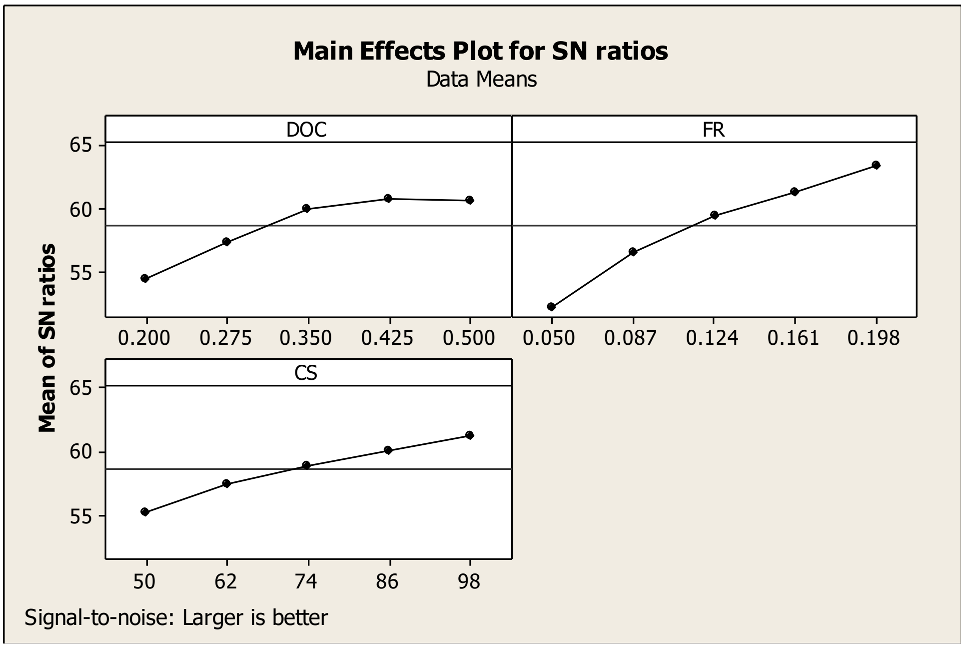

Fig. 2: *Main Effect Plot of MRR for SN Ratios*

Table 3: *Response Table for S/N Ratio for MRR of EN 8 Material.*

Level	Depth of Cut		Feed Rate		Cutting Speed	
	Theoretical	**Software**	**Theoretical**	**Software**	**Theoretical**	**Software**
1	54.46	54.46	52.26	52.26	55.25	55.25
2	57.36	57.36	56.63	56.63	57.53	57.53
3	59.98	59.98	59.77	59.77	58.94	58.94
4	60.77	60.77	61.39	61.39	60.18	60.18
5	60.67	60.67	63.49	63.49	61.34	61.34
Delta	6.32		11.23		6.08	
Rank	2		1		3	

Table 4: *S/N Ratio and Predicted S/N Ratio for MRR of EN 8 Material.*

Sr. No.	Depth of Cut (mm)	Feed Rate (mm/tooth)	Cutting Speed (m/min)	MRR (mm^3/min)	SNRA 1	PSNRA 1
1	0.200	0.050	50	175.28	44.8746	44.6705
2	0.200	0.087	62	366.17	51.2737	51.3130
3	0.200	0.124	74	607.71	55.6739	55.5726
4	0.200	0.161	86	886.85	58.9472	58.7369
5	0.200	0.198	98	1190.29	61.5116	61.9881
6	0.275	0.050	62	297.19	49.4607	49.8461
7	0.275	0.087	74	606.11	55.6510	55.6316
8	0.275	0.124	86	965.71	59.6969	59.7146
9	0.275	0.161	98	1362.85	62.6890	62.7892
10	0.275	0.198	50	921.29	89.2879	58.8041
11	0.350	0.050	74	511.83	54.1825	53.8881
12	0.350	0.087	86	921.29	59.2879	59.4970
13	0.350	0.124	98	1535.48	63.7249	63.4903
14	0.350	0.161	50	869.14	58.7818	59.3286
15	0.350	0.198	62	1572.16	63.9299	63.7031
16	0.425	0.050	86	612.56	55.7430	55.9212
17	0.425	0.087	98	1218.63	61.7174	61.4404
18	0.425	0.124	50	803.92	58.1043	58.1943
19	0.425	0.161	62	1383.32	62.8185	62.3954
20	0.425	0.198	74	1880.18	65.4840	65.9128
21	0.500	0.050	98	710.87	57.0358	56.9708
22	0.500	0.087	50	575.81	55.2056	55.2537
23	0.500	0.124	62	1016.87	60.1453	60.3704
24	0.500	0.161	74	1535.48	63.7249	63.7113
25	0.500	0.198	86	2303.22	67.2467	67.0521

Table 3 shows response table for signal to noise ratio for MRR of EN8 material. This response table represents the effects of various input factors on MRR. Higher the slope in the Main effects plot, corresponding values of delta are higher in the response table. Feed rate has the most significant effect on MRR, according to higher value of delta in response table.

Predicted Value for Signal to Noise Ratio

- ***Lager is Better***

$n = -10 \log_{10} ((1/MRR^2/n))$
$= -10 \log_{10} (3.2548 \times 10^{-05}/1)$
$= 44.8746$

Table 4 shows the values of signal to noise ratio (SNRA) and Predicted signal to noise ratio (PSNRA) for MRR of EN8 material. The values of predicted signal to noise are very much close to the calculated signal to noise values, hence the analysis of Taguchi for signal to noise ratio is correct. The representation of effects of various parameters on MRR and optimized condition is very much nearby.

Analysis for Surface Roughness of Key Way

Taguchi Analysis for Surface Roughness

Figure 3 shows main effects plot for S/N ratio for surface roughness vs. all input factors. Since it is always desirable to minimize surface roughness, 'smaller is better' option is selected. From the above graph, it can be seen that lowest surface roughness is achieved at cutting speed 98 m/min, depth of cut of 0.5 mm and feed rate of 0.05 mm/tooth.

Table 5 shows response table for signal to noise ratio for surface roughness of key way. This response table represents the effects of various input factors on surface roughness. Higher the slope in the main effects plot, corresponding values of delta are higher in the response table. Cutting speed has the most significant effect on surface roughness according to higher value of delta in response table.

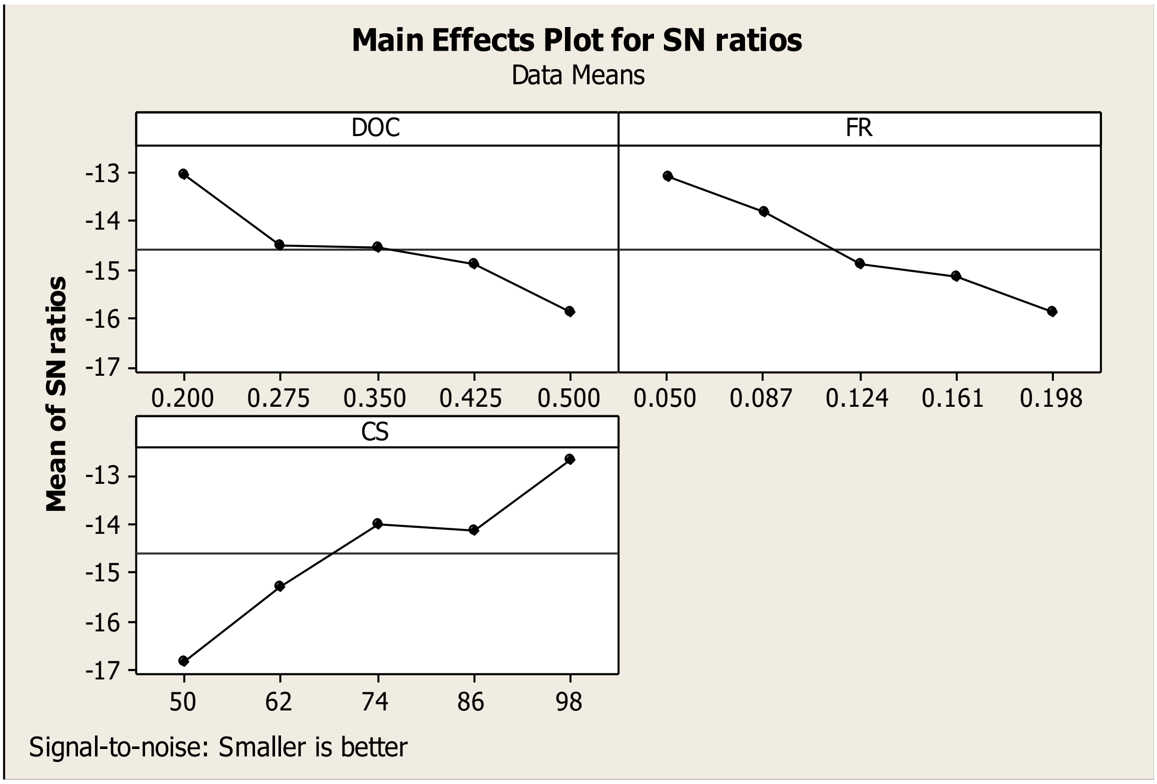

Fig. 3: *Main Effect Plot of Ra for SN Ratios.*

Table 5: *Response Table for S/N Ratios for Surface Roughness of Key Way.*

Level	Depth of Cut		Feed Rate		Cutting Speed	
	Theoretical	Software	Theoretical	Software	Theoretical	Software
1	–13.07	–13.07	–13.08	–13.08	–16.83	–16.83
2	–14.51	–14.51	–13.83	–13.83	–15.29	–15.29
3	–14.56	–14.56	–14.92	–14.92	–13.99	–13.99
4	–14.89	–14.89	–15.16	–15.16	–14.11	–14.11
5	–15.86	–15.86	–15.90	–15.90	–12.68	–12.68
Delta	2.79		2.82		4.15	
Rank	3		2		1	

Table 6: *S/N Ratio and Predicted S/N Ratio for Surface Roughness of Key Way.*

Sr. No.	Depth of Cut (mm)	Feed Rate (mm/tooth)	Cutting Speed (m/min)	Surface Roughness (μm)	SNRA 2	PSNRA 2
1	0.200	0.050	50	4.9	–13.8039	–13.8228
2	0.200	0.087	62	4.85	–13.7148	–13.0375
3	0.200	0.124	74	4.42	–12.9084	–12.8179
4	0.200	0.161	86	4.28	–12.6289	–13.1794
5	0.200	0.198	98	4.12	–12.2979	–12.4963
6	0.275	0.050	62	5.02	–14.0141	–13.7318
7	0.275	0.087	74	4.32	–12.7097	–13.1751
8	0.275	0.124	86	5.60	–14.9638	–14.3748
9	0.275	0.161	98	4.62	–13.2552	–13.1947
10	0.275	0.198	50	7.61	–17.6163	–18.0826
11	0.350	0.050	74	4.03	–12.1061	–12.4729
12	0.350	0.087	86	4.10	–12.2557	–13.3355
13	0.350	0.124	98	4.77	–13.5704	–12.9936
14	0.350	0.161	50	7.54	–17.5704	–17.3845
15	0.350	0.198	62	7.33	–17.3021	–16.5951
16	0.425	0.050	86	4.88	–13.7684	–12.9260
17	0.425	0.087	98	4.24	–12.5473	–12.2471
18	0.425	0.124	50	7.27	–17.2307	–17.4761
19	0.425	0.161	62	5.98	–15.5340	–16.1898
20	0.425	0.198	74	5.88	–15.3875	–15.6289
21	0.500	0.050	98	3.86	–11.7317	–12.4707
22	0.500	0.087	50	7.88	–17.9305	–17.3628
23	0.500	0.124	62	6.24	–15.9037	–16.9145
24	0.500	0.161	74	6.95	–16.8397	–15.8567
25	0.500	0.198	86	7.01	–16.9144	–16.7153

Predicated Vale for Signal to Noise Ratio
Smaller is Better

n=–10 log10 (nose radius^2/n)
=–10 log10 (24.01/1)
=–13.8039

Table 6 shows the values of signal to noise ratio (SNRA) and predicted signal to noise ratio (PSNRA) for surface roughness of key way. The values of predicted signal to noise are very much close to the calculated signal to noise values, hence the analysis of Taguchi for signal to noise ratio is correct. The representation of effects of various parameters on surface roughness of key way and optimized condition is very much nearby.

Regression Analysis: MRR versus DOC, F, Vc

Regression analysis was also carried out for estimating predicted value of material removal rate and surface roughness by using regression equation. Regression analysis also indicates confidence level of practical work performed. It is also used for checking error in the practical by using regression equation formulated for MRR and surface roughness.

The Regression Equation for MRR

MRR=–1406+2021DOC+7279F+10.7Vc

Predictor	Coef	SE Coef	T	P
Constant	–1406.0	229.9	–6.12	0.000
DOC	2021.3	358.6	5.64	0.000
F	7279.5	727.0	10.01	0.000
Vc	10.663	2.241	4.76	0.000

S=190.194 R-Sq=88.0% R-Sq(adj)=86.3%

Practical value of MRR measured for 13 number experiments is 1535.48 (mm^3/min).

MRR=–1406+2021DOC+7279F+10.7Vc
=–1406+2021×0.35+7279×0.124+10.7×98
=1253.55 (mm^3/min)

According to theoretical calculation by regression equation, value of MRR is very close to the practically calculated value.

Regression Analysis: Ra versus DOC, F, Vc

The Regression Equation for Ra

Ra=5.90+5.35DOC+12.2F–0.0512Vc

Predictor	Coef	SE Coef	T	P
Constant	5.9011	0.6679	8.83	0.000
DOC	5.347	1.042	5.13	0.000
F	12.249	2.112	5.80	0.000
Vc	–0.051250	0.006513	–7.87	0.000

S=0.552650 R-Sq=85.3% R-Sq(adj)=83.2%

Practical value of Ra measured for 13 number experiments is 4.77 (µm).

Ra=5.90+5.35DOC+12.2F–0.0512Vc
=5.90+5.35 0.350+12.2 0.124–0.0512×98
=4.27 (µm).

According to theoretical calculation by regression equation, value of Ra is very close to the practically calculated value.

EXPERIMENTAL VALIDATION

L_{25} practical experiments were performed according to Taguchi DOE techniques using MINITAB software and MRR and Ra were calculated for the individual 25 practical. One practical was also performed by taking other parameters without considering already taken five levels for three factors for the experimental validation.

Table 7: *Experimental Validation.*

Sr. No.	Vc (m/min)	Feed Rate (mm/tooth)	DOC (mm)	Time (min)	MRR (mm^3/min)	Ra (µm)
1	92	0.179	0.463	2.55	1805.18	5.71

The Regression Equation for MRR

MRR=–1406+2021DOC+7279F+10.7Vc

MRR=–1406+2021×0.463+7279×0.179+10.7×92
=1817.06 (mm^3/min)

The Regression Equation for Ra

Ra=5.90+5.35DOC+12.2F–0.0512Vc

Ra=5.90+5.35×0.463+12.2×0.179–0.0512×92
=5.85 (µm)

Experimental validation was also carried out by conducting one pilot experiment and measured MRR and surface roughness practically. According to regression equation of MRR and Ra, theoretical values were also calculated. Theoretical values for the MRR and Ra are very close to the practically calculated values.

RESULT AND DISCUSSION

After conducting L_{25} practical experiments according to Taguchi DOE techniques, most effecting parameter for MRR is feed rate followed by depth of cut and cutting speed. While for the surface roughness, it is cutting speed followed by feed rate and depth of cut.

Maximum MRR is obtained at cutting speed 86 mm^3/min, feed rate 0.198 mm/tooth, and depth of cut 0.500 mm; while minimum surface roughness was obtained at cutting speed 98 mm^3/min, feed rate 0.05 mm/tooth, and depth of cut 0.500 mm.

The main goal of research work was to achieve optimum parameters for maximum MRR by compromising surface roughness. So, optimum MRR 1535.08 mm^3/min by maintaining surface roughness 4.77 µm is achieved at cutting speed 98 mm^3/min, feed rate 0.124 mm/tooth, and depth of cut 0.350 mm.

FUTURE SCOPE

With this background, further explorations into this work might include optimization of MRR and Ra by considering change of cutting fluid and tool material.

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