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Multi Objective Optimization of CNC Milling Parameters using Taguchi Method for EN19 & EN24

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Abstract: CNC machine is widely used by manufacturing engineers and production personnel to quickly and effectively set up manufacturing processes for new products .This study discusses an investigation into the use of Taguchi Design methodology for Parametric Study of CNC milling operation for Surface Roughness, Material Removal Rate and Machining time as a response variable. The Taguchi design method is an efficient experimental method in which a response variable can be study, using fewer experimental runs. The control parameters for this operation included: Spindle speed, Feed rate & Depth of cut on EN 19 & EN24 alloy steel. A total of 16 (L_{16} Orthogonal array) experimental runs were conducted using an orthogonal array and the ideal combination of control factor levels was determined for the Surface Roughness, Material Removal Rate and Machining Time. The Taguchi method is to be employed by using MINITAB-16 software to identify the level of importance for the machining parameters.

Keywords: Milling, EN19, EN24, OA, Taguchi Design Method.

1. Introduction

Milling is the process of removing metal by feeding the work past a rotating multipoint cutter. In milling operation the rate of metal removal is rapid as the cutter rotates at a high speed and has many cutting edges. Thus the jobs are machined at a faster rate than with single point tools and the surface finish is also better due to multipoint cutting edges. The action of the milling cutter is vastly different from that of a drill or lathe tool. In milling operation the cutting edge of the cutter is kept continuously in contact with the material being cut. The cuts picks gradually. The cycle of operation to remove the chip produced by each tooth is first a sliding action at the beginning, the cutter comes in contact with the metal and then crushing action takes place just after it leading finally to the cutting actions. The versatility and accuracy of the milling process causes it to be widely used in modern manufacturing.

J.S. Pang [1] et.al introduces the application of Taguchi optimization methodology in optimizing the cutting parameters of end-milling process for machining the halloysite nanotubes (HNTs) with aluminium reinforced epoxy hybrid composite material under dry condition. The result from this study shows that the application of Taguchi method can determine the best combination of machining parameters that can provide the optimal machining response conditions which are the lowest surface roughness and lowest cutting force value. Shokrania [2] et.al analysed the studies on cryogenic CNC end milling of the Inconel 718 nickel based alloy using TiAlN coated solid carbide tools. The experimental investigations revealed that cryogenic cooling has a significant potential to improve surface roughness of machined parts as compared to dry machining without noticeable increase in power consumption of the machine tool. SurasitRawangwong [3] et.al investigated the effect of surface roughness in aluminium semi-solid 2024 face milling. The controlled factors were the speed, the feed rate and the depth of cut which the depth of cut was not over 1 mm. Furthermore, the surface roughness was likely to reduce when the speed was 3,600 rpm and the feed rates was 1,000 mm/min. The result of the research led to the linear equation measurement value which was Ra = 0.205 - 0.000022 Speed + 0.000031 Feed rate. The equation formula should be used with the speed in the range of 2,400 - 3,600 rpm, feed rate in the range of 1,000 - 1,500 mm/min and the depth of cut not over 1 mm.

Lohithaksha M Maiyar [4] et.al investigated the parameter optimization of end milling operation for Inconel 718 super alloy with multi-response criteria based on the Taguchi orthogonal array with the grey relational analysis. Cutting speed, feed rate and depth of cut are optimized with considerations of multiple performance characteristics namely surface roughness and material removal rate. A grey relational grade obtained from the grey relational analysis is used to solve the end milling process with the multiple performance characteristics. Analysis of Variance is applied to identify the most significant factor. Finally, confirmation tests were performed to make a comparison between the experimental results and developed model. N. Satheesh Kumar [5] et.al described the effect of process parameters in turning of Carbon Alloy Steels in a CNC lathe. The parameters namely the spindle speed and feed rate are varied to study their effect on surface roughness. The experiments are conducted using one factor at a time approach. The five different carbon alloy steels used for turning are SAE8620, EN8, EN19, EN24 and EN47. The study reveals that the surface roughness is directly influenced by the spindle speed and feed rate. It is observed that the surface roughness increases with increased feed rate and is higher at lower speeds and vice versa for all feed rates. Vikas [6] et.al studied the comparison of the MRR for EN41 material in a die sinking EDM machine. The various input factors like Pulse ON time, Pulse OFF time, Discharge current and voltage were considered as the input processing parameters, while the MRR is considered as the output. Optimization using Taguchi method was performed to predict the best combination of inputs towards maximum output. MRR plays a very important role in the manufacturing domain as it decides on the time and ultimately cost. Reddy Sreenivasulu [7] focused on the influence of cutting speed, feed rate and depth of cut on the delamination damage and surface roughness on Glass Fibre Reinforced Polymeric composite material (GFRP) during end milling. Taguchi design method is employed to investigate the machining characteristics of GFRP. The obtained results were 5.122µm for surface roughness and 1.692 delamination damage factor.

2. Materials and Methods

2.1 Milling Machine

Computer Numerical Control (CNC) Milling is the most common form of CNC. CNC mills can perform the functions of drilling and often turning. CNC Mills are classified according to the number of axes that they possess. Axes are labeled as x and y for horizontal movement, and z for vertical movement. The number of axes of a milling machine is a common subject of casual "shop talk" and is often interpreted in varying ways. A five-axis CNC milling machine has an extra axis in the form of a horizontal pivot for the milling head, as shown below. This allows extra flexibility for machining with the end mill at an angle with respect to the table. The End Milling may be considering as the combination of peripheral and face milling operations. The cutter has teeth both on the end face and on the periphery. The cutting characteristics may be of peripheral or face milling type according to the particular cutter surface used. When the end cutting edges are only used to remove the metal the direction of rotation and the direction of the helix of the cutter should be same. The end milling is the operation of producing a flat surface which may be vertical, horizontal or at an angle in reference to the table surface.

Fig. 1. HURCO CNC Milling Machine

A six-axis CNC milling machine would have another horizontal pivot for the milling head, this perpendicular the fifth axis. CNC milling machines are traditionally programmed using a set of commands known as G-codes. G-codes represent specific CNC functions in alphanumeric format.

2.2 Work Piece Material

The work material chosen for this experimental work is EN24 and EN19 die steel is shown in Figure 2. It is one of the most widely used die steel material for the manufacture press tools cutting dies and punches for blanking, trimming, flanging and forming operations EN24 is a high carbon alloy steel which achieves a high degree of hardness with compressive strength and abrasion resistance. EN19 is a high quality, high tensile alloy steel usually giving good ductility and shock resisting properties combined with resistance to wear. The chemical composition and properties of EN24 and

EN19 are shown in table 1 & 2.

Fig. 2. EN19 and EN24

Table 1 Composition of EN24 & En19 Steel

S.No	EN24 Die Steel		EN19 Die Steel	
	Elements	% Level	Elements	% Level
1	Carbon	0.36/0.44	Carbon	0.35-0.45
2	Silicon	0.10/0.35	Silicon	0.10-0.35
3	Manganese	0.45/0.70	Manganese	0.50-0.80
4	Sulphur	0.040 max	Chromium	0.50-0.80

5	Phosphorus	0.035 max	Molybdenum	0.20-0.40
6	Chromium	1.00/1.40	-	-
7	Molybdenum	0.20/0.35	-	-
8	Nickel	1.30/1.70	-	-

Table 2 Properties of EN24 & EN19 Die Steel

S. No	Property	EN19	EN24
1	Tensile Strength N/mm²	850-1000	850-1000
2	Yield StressN/mm²	680 Min	654 Min
3	Elongation	13%	13%
4	Impact Izod J	54	40
5	Impact KCV J	50	35
6	Hardness HB	248/302	248/302

2.3 Design of Orthogonal Array

The philosophy of Taguchi shows how the statistical design of experiments can help industrial engineers to design and manufacture the products that are both of high quality and low cost. This approach is primarily focused on eliminating the causes of poor quality and on making product performance insensitive to variation. Taguchi has envisaged a new method of conducting a Design of Experiment which is based on well-defined guidelines. This method uses a special set of arrays called as an orthogonal array. This standard array stipulates the way of conducting minimal number of experiments which could give the full information of all the factors that affects performance parameter. Based on the Taguchi Design Method L_{16}orthogonal array is used for determining the optimal factor settings of a process and thereby achieving improved process performance with reduced process variability and improved manufacturability of products and processes. The crux of the orthogonal arrays method lies in the method of choosing level of combinations of the input design variables for each experiment. The Taguchi method involves reducing the variation in a process through robust design of experiments.

The overall objective of the method is to produce high quality product at low cost to the manufacturer. Taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varies. Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources. The L16 orthogonal array contains 16 experimental runs at various combinations of three input variables. In the present study Table 3 represents various levels of process parameters and Table 4 represents experimental plan with assigned values.

Table 3 Levels of Process Parameters

S. No	Process Parameters	Units	Level I	Level II
1.	Speed	RPM	150	200
2.	Feed	Mm/rev	0.2	0.4
3.	DOC	Mm	0.5	0.1
4	Material	-	EN19	En24

Table 4 Design of Orthogonal Array

Trials	Speed	Feed	DOC	Material
1	150	0.02	0.5	EN19
2	150	0.02	0.5	EN24
3	150	0.02	0.1	EN19
4	150	0.02	0.1	EN24
5	150	0.04	0.5	EN19
6	150	0.04	0.5	EN24
7	150	0.04	0.1	EN19
8	150	0.04	0.1	EN24
9	200	0.02	0.5	EN19
10	200	0.02	0.5	EN24
11	200	0.02	0.1	EN19
12	200	0.02	0.1	EN24
13	200	0.04	0.5	EN19
14	200	0.04	0.5	EN24
15	200	0.04	0.1	EN19
16	200	0.04	0.1	EN24

3. Results And Discussion

Various experiments were performed to find how the output parameter varies with the variation in the input parameters. The results obtained are analysed using S/N Ratios, Response table and Response Graphs with the help of Minitab software. The observations of CNC Milling Process based on Taguchi Orthogonal Array is Shown in table 5.

Table 5 Observations of CNC Milling based on Taguchi orthogonal array

S. No	Speed RPM	Feed mm/rev	DOC mm	Material	MRR mm^3/min	S/N Ratio	RA µm	S/N Rati	Machining Time (sec)	S/N Ratio
1	150	0.02	0.5	EN19	0.082803	-21.6391	0.704	3.0485	20	-26.0206
2	150	0.02	0.5	EN24	0.202323	-13.8791	1.743	-4.8259	17	-24.6090
3	150	0.02	1.0	EN19	0.134466	-17.4278	0.963	0.3275	18	-25.1055
4	150	0.02	1.0	EN24	0.08758	-21.1519	1.318	-2.3983	16	-24.0824
5	150	0.04	0.5	EN19	0.044586	-27.0160	1.320	-2.4115	20	-26.0206
6	150	0.04	0.5	EN24	0.142375	-16.9313	4.392	-12.853	17	-24.6090
7	150	0.04	1.0	EN19	0.134466	-17.4278	1.087	-0.7246	18	-25.1055
8	150	0.04	1.0	EN24	0.103503	-19.7009	3.798	-11.591	16	-24.0824
9	200	0.02	0.5	EN19	0.18686	-14.5697	1.508	-3.5680	17	-24.6090
10	200	0.02	0.5	EN24	0.108005	-19.3311	1.985	-5.9552	20	-26.0206
11	200	0.02	1.0	EN19	0.198539	-14.0431	1.501	3.5276	16	-24.0824
12	200	0.02	1.0	EN24	0.120006	-18.4159	1.872	-5.4461	18	-25.1055
13	200	0.04	0.5	EN19	0.18686	-14.5697	2.221	-6.9310	17	-24.6090
14	200	0.04	0.5	EN24	0.146125	-16.7055	4.068	-12.187	20	-26.0206
15	200	0.04	1.0	EN19	0.095299	-20.4182	2.786	-8.8996	16	-24.0824
16	200	0.04	1.0	EN24	0.098828	-20.1024	3.848	-11.704	18	-25.1055

L_{16}orthogonal array is used to determine the optimal process parameters and Machining results are reported in using S/N ratio. In Taguchi method, there are three performance characteristics such as higher-is-better, nominal-is-better and lower-is-better. Here higher is-better characteristic is used to find the optimal process parameter for MRR, lower-is better characteristic to find the optimal parameter for SR and Machining Time. The response table and response graph for MRR, SR and Machining Timeis listed in Table 6, 7 & 8 and Figure 3, 4 & 5.

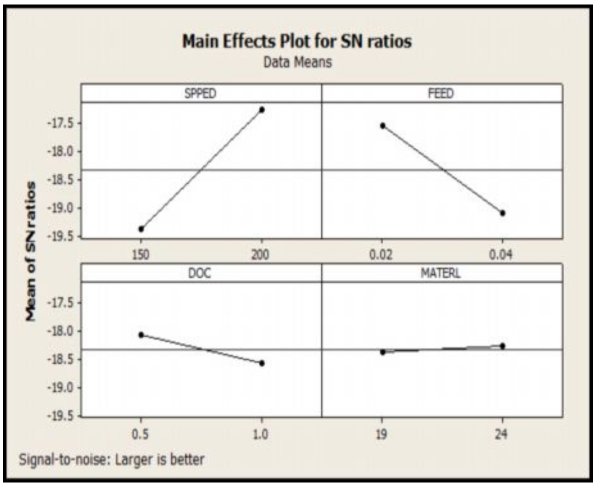

Fig. 3. S/N Ratios for MRR

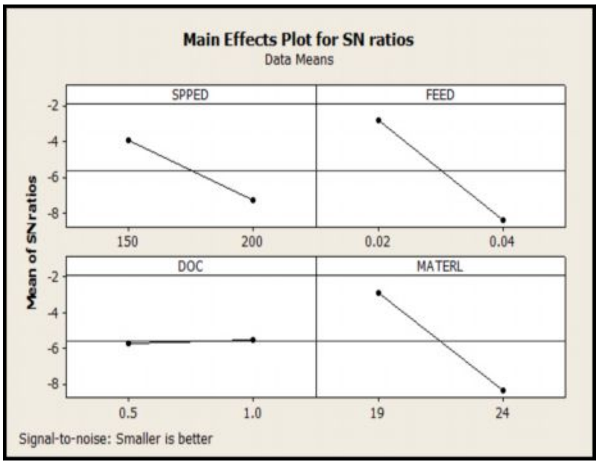

Figure 4 S/N Ratios for SR

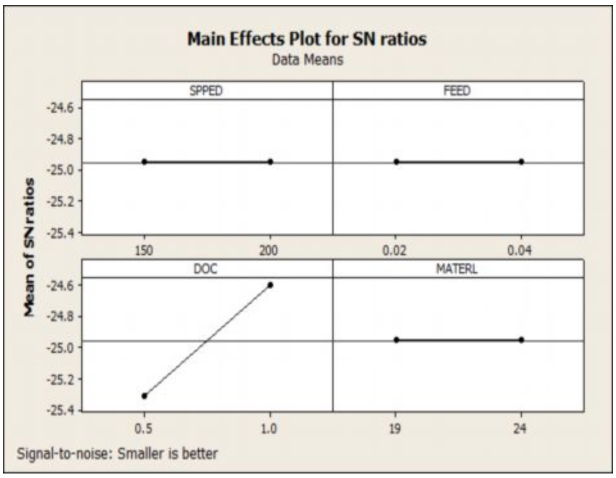

Figure 5 S/N Ratios for Machining TimeTable 6 Response Table for MRR

Table 6 Response Table for MRR

Level	Speed	Feed	DOC	Material
1	-19.40	-17.56	-18.08	-18.39
2	-17.27	-19.11	-18.59	-18.28
DELTA	2.13	1.55	0.51	0.11
RANK	**1**	**2**	**3**	**4**

Table 7 Response Table for SR

Level	Speed	Feed	DOC	Material
1	-3.929	-2.793	-5.710	-2.836
2	-7.277	-8.413	-5.496	-8.370
Delta	3.349	5.620	0.215	5.534
Rank	**3**	**1**	**4**	**2**

Table 8 Response Table for Machining Time

Level	Speed	Feed	DOC	Material
1	-24.95	-24.95	-25.31	-24.59
2	-24.95	-24.95	-24.59	-24.59
Delta	0.00	0.00	0.72	0.00
Rank	**2**	**2**	**1**	**2**

4. Conclusion

The following conclusions are drawn based on the performance of machining characteristics namely Surface Roughness, Material Removal Rate and Machining time has the best optimal set of parameters and the significance percentage of contribution for the parameter over the responses are,

- Speed = 200 RPM; Feed = 0.02 mm/rev; Depth of cut = 0.5mm and for Material = EN 19. Spindle speed effect has more influence on material removal rate with 82.604%.
- Speed = 150 RPM; Feed = 0.04 mm/rev; Depth of cut = 1.0 mm and for the Material = EN 19 and feed rate gave 40.28% of effect over response.
- For machining time, Depth of cut alone have an impact over response where else Spindle speed, Feed rate of two levels can be used for least machining time. The percentage of contribution of Depth of cut over the Machining time is **74.28%.**

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