Taguchi Analysis on Cutting Forces in Milling OHNS with Carbide Insert

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Abstract – *OHNS is high carbon steel and its machining is hindered basically due to higher hardness value. The present experimental work is focused on optimizing the machining parameters in milling OHNS material with carbide insert for a best parametric combination to render the lowest cutting force using a Taguchi method. The cutting speed, feed rate & depth of cut were used as process parameters where as Cutting force is selected as performance characteristics. Based on Taguchi's L9 orthogonal array, nine experimental runs have been executed, accompanied by ANOVA method to solve the multi-response optimization problem. Based upon S/N ratio values & ANOVA results, best levels of parameters have been identified. The percentage contribution of influence of each process parameter on individual performance characteristic was analyzed with the help of experimental results obtained using Taguchi Method. The depth of cut and speed were identified as the most influential process parameters on cutting forces.*

Key Words: *Cutting force, Surface Roughness, Taguchi Method, ANOVA, and Optimization*

1. INTRODUCTION

Milling is the process of machining flat, curved, or irregular surfaces by feeding the work piece against a rotating cutter containing a number of cutting edges. The milling machine consists basically of a motor driven spindle, which mounts and revolves the milling cutter, and a reciprocating adjustable worktable, which mounts and feeds the work piece. The cutter may also be held at an angle relative to the axis of the tool [2]. Milling covers a wide variety of different operations and machines, on scales from small individual parts to large, heavy-duty gang milling operations. It is one of the most commonly used processes for machining custom parts to precise tolerances. The integration of milling into turning environments, and vice versa, begun with live tooling for lathes and the occasional use of mills for turning operations. This led to a new class of machine tools, multitasking machines (MTMs), which are purpose-built to facilitate milling and turning within the same work envelope. The aim of the present experimental investigation is to determine the optimal levels of process parameters for optimizing the cutting forces & surface quality of OHNS high carbon steels by employing Taguchi's orthogonal array design and Analysis of Variance (ANOVA). The literature survey has revealed that several researchers attempted to calculate the optimal cutting conditions in milling operations. This study aimed at evaluating the best process environment which could simultaneously satisfy requirements of both quality and as well as productivity.

1.1 Taguchi Method

Taguchi has envisaged a new method of conducting the design of experiments which are based on well-defined guidelines. This method uses a special set of arrays called orthogonal arrays. These standard arrays stipulate the way of conducting the minimal number of experiments which could give the full information of all the factors that affect the performance parameter [1]. The crux of the orthogonal arrays method lies in choosing the level combinations of the input design variables for each experiment. The L9 orthogonal array is meant for understanding the effect of 4 independent factors each having 3 factor level values. This array assumes that there is no interaction between any two factor. The design of experiments using the orthogonal array is, in most cases, efficient when compared to many other statistical designs. The minimum number of experiments that are required to conduct the Taguchi method can be calculated based on the degrees of freedom approach.

1.2 S/N Ratio (Signal-to-Noise ratio)

Taguchi come out with a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. Taguchi recommends the use of the loss function to measure the performance characteristics deviating from the desired value. The value of the loss function is further transformed into a signal-to-noise ratio [3]. There are three categories of the performance characteristics in the analysis of the S/N ratio, that is

a) The smaller- the- better

b) The nominal-the-better

c) The larger-the-better

The S/N ratio for each level of process parameters is computed based on the S/N analysis, regardless of the category of the performance characteristic.

(a) The smaller-the-better

The smaller-the-better characteristics is one in which the desired goal is to reduce the measured characteristics to zero. This applies, for instance to the porosity, vibration, the consumption of an automobile, tool wear, surface roughness, response time to customer complaints, noise generated from machine or engines, percent shrinkage, percent impurity in chemicals, and product deterioration.

$$\frac{S}{N} = -10\log(M.S.D) = -10\log\frac{1}{m}\Sigma Ti^2$$

Where MSD is the mean standard deviation,

m is the number of tests,

Ti is the experiment number

1.3 Analysis Of Variance (ANOVA)

This method was developed by Sir Ronald Fisher in the 1930s as a way to interpret the results from agricultural experiments. ANOVA is not a complicated method and has a lot of mathematical beauty associated with it. ANOVA is a statistically based, objective decision-making tool for detecting any differences in average performance of groups of items tested [4]. The decision, rather than using pure judgment, takes variation into account. A statistical analysis of variance (ANOVA) is performed to see which process parameters are statistically significant. With the *S/N* and ANOVA analyses, the optimal combination of the process parameters can be predicted.

The mathematical relations are:

- ✓ **Average**:(SN1+SN2+SN3+SN4+SN5+SN6+SN7+SN8 +SN9)/9
- ✓ **Degree Of Freedom:** (DOF) = LEVEL-1
- ✓ **Sum of Squares:(Speed, feed, doc)**

Sum of square between groups=Sum of squares total – Sum of the square with in groups

- ✓ **Mean of squares:** Sum of squares/DOF
- ✓ **Sum of Squares of Error**=(SSt-(SSd1+SSd2+SSd3))

SSt – Sum of squares of total

SSd1- sum of squares of speed

SSd2- sum of squares of feed

SSd3- sum of squares of depth of cuts

- ✓ **Mean squares of Error** = (sum of squares of error/ DOF)
- ✓ **Percentage**= (Sum of squares/ sum of squares of Total)

2. WORK MATERIAL, INSERT & HOLDER

2.1 OHNS (Oil hardening Non-Shrinking Die Steel / Oil hardened Nickel Steel)

OHNS is a high Carbon steel, it is an ideal type oil-hardened steel which is economical and dependable for gauging, cutting and blanking tools as well as can be relied for hardness and good cutting performance. OHNS steel refers to a variety of carbon and alloy steels that are particularly well-suited to be made into tools. Their suitability comes from their distinctive hardness, resistance to abrasion, their ability to hold a cutting edge, and/or their resistance to deformation at elevated temperatures (red-hardness). Generally used in a heat-treated state. Further, it also has a low hardening temperature (and, therefore, can be heat treated in homes and shops), and does not lose shape during quenching. It is inexpensive and readily available. OHNS is ideal for making tools and knives, as it can be easily sharpened.

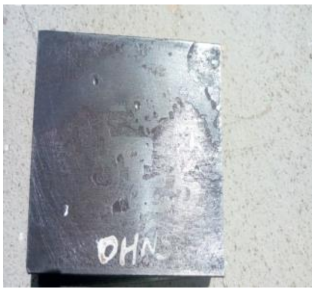


Fig-1: OHNS Material

2.2 Insert & Tool Holder

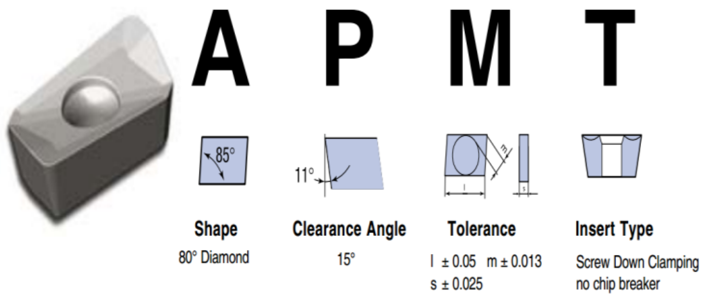


Fig-2: APMT1604 Insert nomenclature

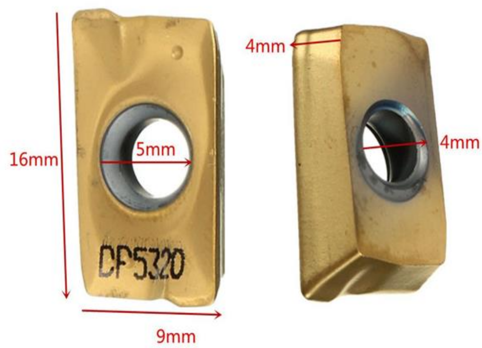


Fig-3: Insert dimensions

Fig-4: Tool Holder (T- Max End Mill Cutter)

3. EXPERIMENTAL WORK & DATA

Table-1: Process Variables and Their Levels

SYMBOL	PARAMETER	LEVLES		
		1	2	3
A	SPEED(rpm)	385	685	960
B	FEED(mm/min)	18	29	45
C	DEPTH OF CUT(mm)	1.0	1.5	2.0

Table-2: Process Variables and Their Levels, L9 Orthogonal Array

Exp. No	Variable 1	Variable 2	Variable 3	SPEED	FEED	DEPTH OF CUT
1	1	1	1	385	18	1.0
2	1	2	2	385	29	1.5
3	1	3	3	385	45	2.0
4	2	1	2	685	18	1.5
5	2	2	3	685	29	2.0
6	2	3	1	685	45	1.0
7	3	1	3	960	18	2.0
8	3	2	1	960	29	1.0
9	3	3	2	960	45	1.5

Table 1 shows the process variables and heir levels in this experiment. Table 2 shows the L9 orthogonal array with process parameters and their levels. Total 9 experiments have been executed on Universal milling machine. While machining cutting forces are measured with help of Dynamometer set up as shown in Fig:

Fig-5: Universal Milling Machine With Dynamometer

Fig-6: Dynometer Setup

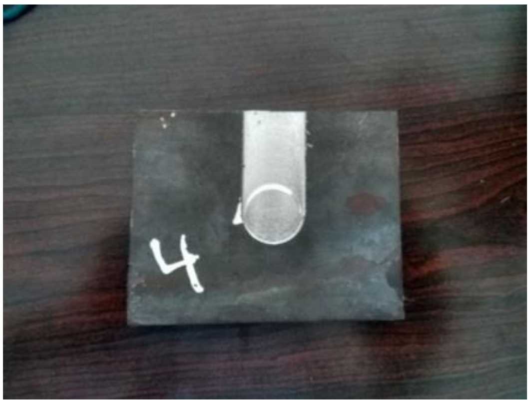


Fig-7: OHNS Work Piece After Machinig

Fig 7 shows the OHNS material after machining. Table 3 shows the measured cutting force values in 3 directions, i.e. Fx-Feed force, Fy-Tangential Force, Fz- Cutting force.

Table-3: Cutting Forces of OHNS

Level/ Process Parameters	Mean Values of Cutting forces				
	A	B	C	MAX-MIN	RANK
1 (Speed)	-32.560	-27.027	-28.345	5.541	2
2 (Feed)	-29.196	-28.493	-27.899	1.29	3
3 (Depth of cut)	-25.908	-29.749	-32.274	6.366	1

Table–4: OHNS S/N ratio values

EXP NO	Fx (Feed force)	FY (Tangential force)	FZ (Cutting force)
1	24.525	84.28	70.662
2	63.765	79.461	`141.264
3	59.841	73.575	206.01
4	58.86	29.43	88.29
5	29.43	23.544	88.29
6	12.753	22.563	39.24
7	59.841	44.145	103.005
8	45.126	36.297	74.556
9	17.278	15.696	62.784

4. CALCULATIONS

4.1 S/N Ratio values

Table-5: Mean values of cutting forces

Run NO	Parameter Level			Experiment Results	S/N Ratio
	V	F	D	F_Z=Newton	
1	1	1	1	70.662	-27.487
2	1	2	2	`141.264	-33.458
3	1	3	3	206.01	-36.735
4	2	1	2	88.29	-29.375
5	2	2	3	88.29	-29.375
6	2	3	1	39.24	-22.332
7	3	1	3	103.005	-30.714
8	3	2	1	74.556	-27.907
9	3	3	2	62.784	-26.414

Table-6: Optimum solution for OHNS

Process Parameters	Optimum Levels for Surface finish
Speed	A_2
Feed	B_3
Depth of Cut	C_1

4.2 Calculation of ANOVA

1) Average:

(SN1+SN2+SN3+SN4+SN5+SN6+SN7+SN8+SN9)/9

= -29.050

2) Degree Of Freedom (DOF) = LEVEL-1 =3-1 =2

3) Sum of Squares between groups:

Sum of square between groups= sum of squares total-sum of the square with in groups

i. Speed: SS_d1= 16.705
ii. Feed: SS_d2 = 0.841
iii. Depth of cut: SS_d3 = 20.55

4) Mean of squares: Sum of squares/DOF

i. Speed = 8.35
ii. Feed = 0.42
iii. Depth of cut = 10.275

5) Sum of Squares of Total

SSt = 39.318

6) Sum of Squares of Error = (SSt-(SSd1+SSd2+SSd3))

SSe = 1.22

7) Mean squares of Error = (sum of squares of error/ DOF) MSe = 0.61

8) Percentage = (Sum of squares/sum of squares of Total)

i. Speed = 16.075/2.186 = 0.42 = 42%
ii. Feed = 0.841/39.018 = 0.02 = 2%
iii. Depth of cut = 20.550/39.018 = 0.52 =52%
iv. Error =1.222/39.318 = 0.03 = 3%

5. RESULTS AND DISCUSSIONS

The main objective of the experiment is to optimize the milling parameters (cutting speed, feed rate, depth of cut) to achieve low value of the cutting forces. The experimental data for the cutting values are shown in Table 3, for OHNS Steel. The S/N ratio values of the cutting forces are calculated, using the smaller the better characteristics are shown in Table 4, Analysis of variance for S/N ratio, Taguchi recommends analyzing data using the S/N ratio that will offer two advantages

1) It provides guidance for selection of the optimum level based on least variation around on the average value, which closest to target

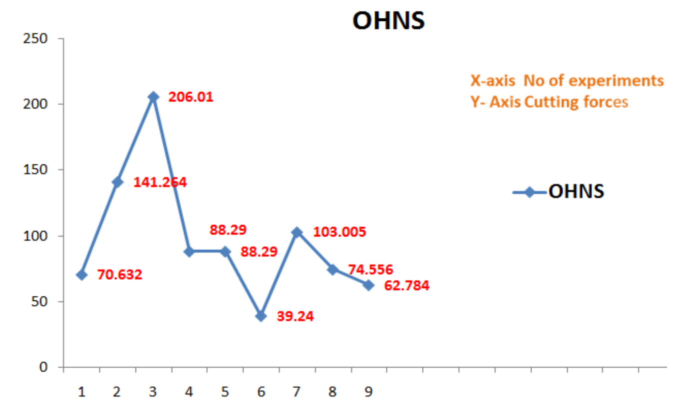
2) Also it offers objective comparison of two sets of experimental data with respect to deviation of the average from the target.

- From the ANOVA, Table 7 and the Percentage value, the depth of cut is the only significant factor which contributes to the Cutting force i.e., 52 % contributed by the cutting speed on surface roughness.
- The second factor which contributes to cutting force is the speed rate having 42 %.
- The third factor which contributes to cutting force is the feed having 2%.
- The validation experiment confirms that the error occurred was 3%, which is less than 9.4%.

Symbol	Parameter	DOF	Sum of squares	Mean of squares	%
A	Speed	2	16.705	8.35	42%
B	Feed	2	0.841	0.42	2%
C	Depth of cut	2	20.55	10.275	52%
	Error	2	1.222	0.61	3%
				Total	= 100%

Table-7: ANOVA results for OHNS

The optimum turning parameters are speed 685rpm, feed 45mm/rev and depth of cut 1.0mm for OHNS material by using APMT carbide insert. The different values of the S/N ratio between maximum and minimum shown in table 5. The effect and contribution of the 3 parameters are identified and ranked according to their percentage. The response table is given as per the average of S/N ratio. The optimum levels of cutting force shown in table 6. The cutting speed and the depth of cut are two factors with the highest different in values significance 42% and 52% respectively, Table 7. Based on Taguchi prediction that the bigger different in value of S/N ratio shows a more effect on cutting forces or more significant. Therefore, it can be concluded that, increase changes the Depth rate reduces the cutting forces significantly.



Graph-1: Cutting forces of OHNS

The above Graph 1 shows the variation of cutting forces for OHNS material. Lower value recorded at 6th level i.e., 39.24KN

6. CONFIRMATION TEST

As the optimum levels are obtained at the same levels selected in the experiment. For OHNS the cutting force value 39.24N which is minimum. Experiment number 6 i.e., (A_2, B_3, C_1) Speed -685rpm, Feed- 45mm/min, Depth of cut – 1.0mm are the best combination for machining. Hence it is confirmed that the value obtained is appropriate.

7. CONCLUSION

The present investigation aimed at optimization of cutting forces during milling of OHNS work piece with carbide inserts. This analysis was carried out by developing cutting forces models of Newton based on L9 orthogonal array in Taguchi optimization technique. So, now it is found, how to use Taguchi's parameter design to obtain optimum condition with lowest cost, minimum number of experiments

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