SELECTION of OPTIMAL CUTTING PARAMETERS in END MILLING PROCESS USING TAGUCHI METHOD

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Abstract

The present completion of our project is selection of optimal cutting parameters using Taguchi method. The end milling of SUS304 stainless steel using carbide tool was investigated. A combined technique using orthogonal array and analysis of variance was employed to investigate the contribution and effects of spindle speed, feed rate, and depth of cut for axial and radial on cutting force parameters. The effect of selected process parameter and its level on the cutting force and the subsequent optimal setting of the parameters have been accomplished using Taguchi's parameter design approach. Taguchi orthogonal arrays signal to noise (S/N) ratio and analysis of variance (ANOVA) are used to find out the optimal levels and the effect of the process parameters on cutting force. The estimation of the optimum performance characteristics of end milling of the optimum levels of parameters is done in this project and the results are verified by confirming with practical experiments. It can be concluded that Taguchi method is very suitable in solving the cutting force in end milling.

1. INTRODUCTION:

Strategic growth and competitiveness of organizations are depending upon the effective utilization of the critical productive resources of the organization. Production is concerned with design and control systems responsible for the productive use of raw materials, human resources, equipment and facilities in the development of the product.

Production is a creation of utility. The production function creates utility by providing form, time and place utilities for the produced goods. Manufacturing provides form utility while physical distribution provides the time and place utilities. Production system of an organization is the part which produces the organization products. Production is the basic activity of all organizations and all other activities revolve around production activity. The output of production is the creation of goods which satisfies the needs of the customer.

The present trend is to achieve the highest possible quality of the product at the lowest cost. The quality of products manufactured can be ensured, provided stable and reliable operation of the manufacturing equipment is possible. Hence the study of accuracy of the manufacturing process is vital to ensure the choice of an economical manufacturing method. When one thinks as to how the varies components of machines are produced, many techniques come to the mind, for example casting, forging, machining, etc. the manufacturing processes are so varied that simple and universally accepted criteria.

In machining process as known as metal cutting process the material is removed from the work piece to get the final shape of the product.

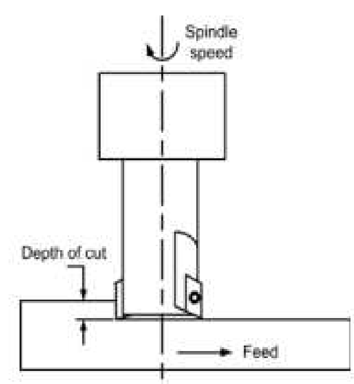


Fig.1.1 End milling operation

The milling operation is extremely used in many applications; the aerospace and automobile industries are clear instances. A variety of applications can range from very simple to final parts with complex geometry and shape, and high level of precision and surface qualities. In general more complex to model milling than other types of machining processes. End milling is aim to removing material by two continuous motions. Those of the tool and work pieces, basically the tool has rotating motion (spindle speed) and the work pieces is linear ones (feed rate) as shown in Fig.1.1.

2. LITERATURE REIVIEW

In the past few years, many studies have been focused on optimizing the cutting process in end milling.

Tsai et al.[1] searched for how to select the optimal cutting parameters for high-speed machining of hardened molding alloy with maximum material rate.

Juan.H,[2] Studied the optimization design of cutting parameters for rough milling with high–speed machining tool steels to achieve minimum production cost.

D'Errico et al.[3] Evaluated coating performance of tools under the high speed end milling process based on a selected index of processing cost per unit metal removal volume.

Ghani et al.[4] Economic benefits of finish milling using coated carbide tools have been investigated to identify the combination of cutting speed, feed, depth of cut and tool material for a finish milling operation, with useful tool life being taken when the cutting force deteriorated beyond a predetermined level.

Bidhendi et al. [5] Machinability selected the minimum production cost, minimum production time, and maximum profile rate as object functions to search for the optimum parameters to improve machining efficiency.

Ghani et al. [6] used the Taguchi method in the optimization of end milling process parameters. They applied it to optimize cutting parameters in end milling when machining hardened steel with a tin-coated carbide insert tool under the semi finishing and finishing conditions of high-speed cutting.

Reedy et al. [7] have developed a surface roughness model for the end milling of medium carbon steel. The mathematical models are further utilized to find the optimum process parameters using genetic algorithms.

Ghani et al. [8] used Taguchi optimization methodology to optimize the cutting parameters in end milling when machining hardened steel AISIH13 with Tin coated p10 carbide insert tool under semi finishing and finishing condition of high-speed cutting.

In the present work, an attempt has been made to evaluate the contribution of cutting parameters during machining on the work piece cutting forces Using Taguchi method for optimization of end milling process parameters.

3. Experimental setup:

The experimental investigation presented here was carried out on a vertical milling machine (Nam Mill) with multiple tool change capability (max 21 tools) and 3 HP spindle horse power and 440V. The machine is capable of three axis movement (along X, Y and Z directions). The work piece is used for investigation was SUS304 stainless steel, with chemical composition of c- 0.03 to 0.25%, si – 1 to 2 %, ni - 3.5 to 22%, mn – 2 to 10%, cr – 16 to 26%. SUS304 stainless steels are most commonly used for all forms of close tolerance shafting, e.g. hydraulic shaft , pump shaft, piston rods, sprockets and springs, cylinders, watches, water heater, furniture, keys,etc.

Fig no: 3.1 Experimental setup

In this experiment, in order to investigate the cutting force during the machining the component. Because low cutting force may not able to remove metal and machining time will also increase more. Whereas the cutting force is more in the sense, it cause machine to vibrate more, increases tool wear, increases the power consumption and results in poor surface finish. During cutting of the SUS304 stainless steel, solid carbide tool was used. A view of cutting zone arrangement is shown in fig. the cutting force of the machining work piece was measured with the help of a strain gauge based milling tool dynamometer.

4. EXPERIMENTAL DESIGN:

A fully factorial experimental uses all the possible combinations of a number of factors at their levels to arrive at an outcome. But more efficient test plans, as developed by statisticians, fractional factorial experiments (FEES) use only a portion of the total combinations to estimate the main factor effects and some, not all, of the interactions. Certain treatment conditions are chosen to maintain the orthogonality among the various factors and interactions.

According to Taguchi, depending upon number of levels in a factor, a 2 or 3 level orthogonal arrays (OA) can be selected. In this situation a possible matrix is a 9 trail OA which is labeled as L9 matrix. The 9 trails provide 8 degrees of freedoms for the entire experiment. L9 orthogonal array is shown in table. Based on this table the input value of machine is arranged. And then the machine is machining the component. During the machining the cutting force was measured by using milling tool dynamometer. After each test completed cycle time was calculate by using stopwatch. Calculate the metal removal rate also. Then after collecting all the data for all combination of each factor was calculated and the best parametric level along with confidence intervals were established.

4.1 *Factors range & levels:*

In the project using four factors and three levels are taken for conducting the experiments.

Table: 4.1 Factors range and levels

SERIAL NO	FACTORS	LEVEL 1	LEVEL 2	LEVEL 3
1	Speed(V) (rpm)	200	400	600
2	Feed(F) (mm/min)	0.5	0.75	1
3	Axial diameter(D_a) (mm)	0.5	1	1.5
4	Redial diameter(D_r) (mm)	0.5	1	1.5

4.2 Selection of L9 orthogonal array:

Selecting an orthogonal array depends on the total degrees of freedom for the corresponding factors. For a factor with a level of 3, the degrees of freedom are 2 that is number of level-1. In this experiment, there are three factors with level number 3. Consequently, the total degrees of freedom are 8. In the mean time, the interaction between the cutting Parameters are neglected here. Thereby, a L9 orthogonal array is used. The experimental layout is shown in table.

According to the listed combinations of cutting conditions, work pieces of SUS304 stainless steel are cut for 30mm long. Then the cutting force is measured and the cutting time is counted. Finally optimize the cutting force parameter and metal removal rate are calculated.

Table: 4. 2. L9 orthogonal arrays

TRAIL NO	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	3	2
5	2	2	1	3
6	2	3	2	1
7	3	1	2	3
8	3	2	3	1
9	3	3	1	2

4.3 *Experimental L9 array & readings:*

Once the parameters are assigned to a particular column of the selected orthogonal array, the factors at different levels are assigned for each trail. The assigned experimental array is shown in table

Table: 4.3 Experimental L9 array

S NO	Speed(v) (rpm)	Feed (f) (mm/min)	Axial Depth(mm)	Radial Depth(mm)	Cutting Force(N)	Cutting Time(min)	MRR mm^3/s
1	200	0.5	0.5	0.5	24	21	1.90
2	200	0.75	1	1	45	24	1.70
3	200	1	1.5	1.5	20	27	1.48
4	400	0.5	1.5	1	26	20	2
5	400	0.75	0.5	1.5	30	16	2.5
6	400	1	1	0.5	28	18	2.23
7	600	0.5	1	1.5	10	15	2.67
8	600	0.75	1.5	0.5	15	12	3.34
9	600	1	0.5	1	27	13	3.07

4.4 Tabulation for S/N ratio:

The cutting forces are "lower the better" type of quality characteristics. Lower the better S/N ratios were computed for each of the 9 trails and the values are recorded in table.

Lower is better: S/N ratio = $-10 \log (1/r \sum y_i^2)$

For example, for trail no. 1, the S/N ratio is:

S/N ratio = -10 log (1/3(23+20+29)) = -27.7

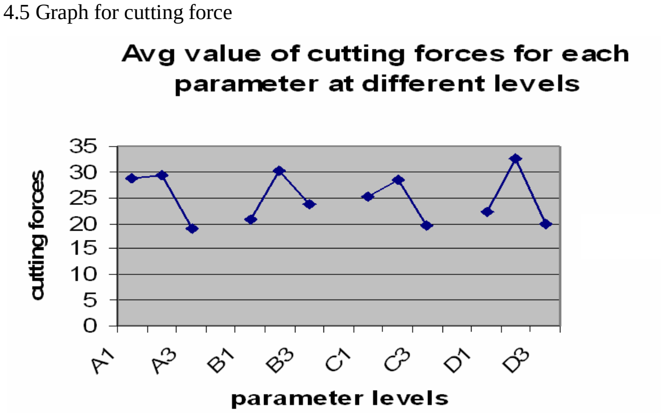
TABLE: 4.4 S/N ratios:

TRAIL NO	CUTTING FORCES in Newton				
	Replicate No 1	Replicate No 2	Replicate No 3	Average	S/N ratio
1	23	20	29	24	-27.7
2	40	45	50	45	-33.09
3	23	17	20	20	-26.08
4	23	27	28	26	-28.32
5	37	27	26	30	-29.35
6	28	29	27	28	-28.94
7	7	15	8	10	-20.51
8	15	19	11	15	-23.72
9	35	25	21	27	-28.82

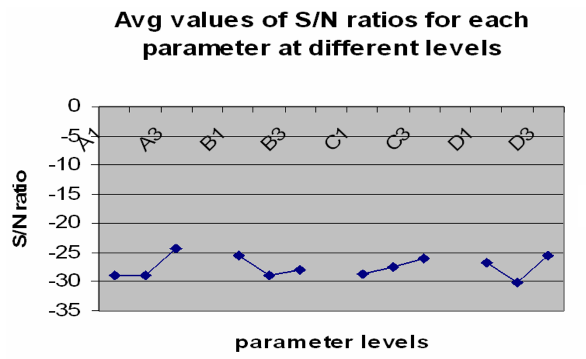
Table: 4.5 Average values of cutting force & S/N ratios

FACTORS	LEVEL 1		LEVEL 2		LEVEL 3	
	C F	S/N ratio	C F	S/N ratio	C F	S/N ratio
A	28.66	-28.95	29.33	-28.97	19	-24.35
B	20.66	-25.51	30.33	-28.82	23.66	-27.94
C	25.33	-28.72	28.33	-27.51	19.66	-26.04
D	22.33	-26.78	32.66	-30.07	20	-25.41

4.5 Graph for cutting force



4.6 Graph for S/N ratio



5. ANALYSIS OF EXPERIMENTAL RESULTS:

It is clear from above figures that the cutting forces are minimum at the third level of parameter A (A3), first level of parameter B(B1), third level of parameter C(C3), third level of parameter D(D3).In order to study the significance of the parameters, three way analysis of variance (ANOVA) was performed for cutting forces. The Results are shown in the table (7&8) It is clear from previous graph, that the S/N ratios are maximum at the third level of parameter A (A3), first level of parameter B(B1), third level of parameter C(C3), third level of parameter D(D3). In order to study the significance of the parameters, three way analysis of variance (ANOVA) was performed for S/N ratios. The Results are shown in the table.

5.1 ANOVA for cutting force

The total variation present in the process is decomposed to following components:

1. Variation due to factor A
2. Variation due to factor B
3. Variation due to factor C
4. Variation due to factor D
5. Variation due to error

Total variation

$SS_T = [\sum yi^2] - T^2/N$

$SS_T = (24^2 + \ldots\ldots\ldots\ldots + 27^2) - 5625$

$= 789.93$

Variation due to error

$SS_e = SS_T - [SS_A + SS_B + SS_C + SS_D]$

SOURCE	SUM OF SQUARE (SS)	DEGREES OF FREEDOM (v)	VARIANCE (V)	F - RATIO	EXPECTED (SS')	PERCENT CONTRIBUTION (P) %
A	268.66	2	134.33	824.11	268.33	33.96
B	150	2	75	460.12	149.67	18.94
C	98.66	2	49.33	302.6	98.33	12.4
D	269.66	2	134.83	827.17	269.33	34.09
E	2.95	18	0.163		4.27	0.61
Total	789.93	26			789.93	100

5.2 ANOVA for S/N ratio:

SOURCE	SUM OF SQUARE (SS)	DEGREES OF FREEDOM (v)	VARIANCE (V)	F - RATIO	EXPECTED (SS')	PERCENT CONTRIBUTION (P) %
A	42.56	2	21.28	170.24	42.31	40.09
B	17.65	2	8.82	70.56	17.40	16.48
C	14.84	2	7.42	59.36	14.59	13.82
D	28.20	2	14.10	112.8	27.79	26.33
E	2.25	18	0.125		3.43	5.28
Total	105.52	26			105.52	100

6. INTERPRETATION METHODS:

Once the experiment has been conducted, the ANOVA is carried out using the results of the experiments. The significant factors was identified, graphs are plotted for varies trail conditions and the parameters which significantly influence the mean and variation in the cutting force were determined. However, the results obtained so far are not sufficient enough to find the optimum parameters in order to minimize the cutting force.

Hence, some more information is required to conclude with an optimum parameter set. These sets of pieces of information are obtained using the interpretation methods

1. percent contribution
2. estimating mean
3. confidence interval around the estimated mean

1. Percent contribution

The percent contribution is the portion of the total variation observed is an experiment attributed to each significant factor is reflected. The percent contribution is a function of the sums of squares for each significant item; it indicates the relative power of a factor to reduce the variation. If the factors levels were controlled precisely, then the total variation could be reduced by the amount indicated by the present contribution. The variation due to a factor contains some amount due to error; it is represented by the following form for factor A given below:

$$V_A = V'_A + V_{error}$$

Where V'_A is the expected amount of variation due solely to factor A given below:

$$V_A = SS'_A / \nu_A$$

$$V'_A = SS'_A / \nu_A$$

$$SS'_A = SS_A - (V_e)(\nu_e)$$

Percent contribution (P) = $(SS'_A/SS_T) * 100$

The expected figure of the sums of square for each factor is computed by using the percent contribution (P) for each factor and is calculated for cutting force and S/N ratio, as shown in tables respectively.

2. *Estimating the mean (µ):*

Once an experiment is conducted and the optimum treatment condition with in the experiment is determined, one of two possibilities exists:

1. the prescribed combination of factors level is identical to one of those in the experiment
2. the prescribed combination of factors level was not included in the experiment

In this work, the first situation exists, and, hence, the most direct way to estimate the mean for that treatment condition is to average all the results for the trails which are set at those particular levels.

The estimation of mean for cutting force is achieved by following equation:

$$\mu = T + (A3-T) + (B1-T) + (C3-T) + (D3-T)$$

When 'T' is the average value of cutting force,

$$T = 25$$

$$\mu = 25 + (19-25) + (20.66-25) + (19.66-25) + (20-25)$$

$$= 25-6-4.34-5.34-5$$

$$= 4.32$$

3. Confidence interval around the estimated mean:

The estimate of the mean (µ) is only a point estimate based on the average of the result obtained from the experiment statically this provides a 50% chance of the true average being greater then µ and a 50% chance of the true average being less than µ .the confidence level is the maximum and minimum value between which the true average should fall at some stated percentage of confidence .there are three types of confidence interval (CIs) that Taguchi method represent, depending on the purpose of the estimate .in this work ,confidence interval (CI_2) around the estimated mean of treatment condition used in a confirmation experiment to predictions follows the formula given below :

$$CI = \sqrt{((F_\alpha, 1, \nu_2)\, V_e)/efficiency}$$

Efficiency = N/ (1+total dof associated with item used in 'µ')

Where α is the level of risk ,Ve is the error variance ,Ve is the degree of freedom for the error ,ηeff is this effective number of replication and r is number of test trials

When,

$$N = 9$$

$$F_{95\%}, 1, 18 = 4.41$$

$$V_{error} = 0.165$$

$$Efficiency = 9/ [1+ (2+2+2+2)] = 1$$

$$CI = \sqrt{(4.41*0.165)/1} = 0.853$$

Finally, the estimated average with the confidence internal at 95%confidence is,

$$4.32 - 0.853 \le \mu \le 4.32 + 0.853$$

$$3.466 \le \mu \le 5.173$$

7. CONFIRMING EXPERIMENTS:

The Confirming experiments are used to verify that the factors and levels chosen from an experiment cause a product or process to behave in a certain fashion .the conforming is highly recommended to verify the experimental

conclusion and is interpreted and is this manner .if the average of the result of the confirmation is with in the limits of the confidence limits, then the significant factors as well as the appropriate levels for obtaining the desired Results are properly chosen. if the average of the results of the confirmation experiment is outside the limits of the stainless steel. Then the parameters selected and levels to control the results for a desired value are wrong or have excessive measurements.

Three confirmation experiments are conducted at the optimum settings of the process parameters recommended by the investigation .the average of the respondents cutting force in each experiment is found to be 4.63%; the result was with in the CI of the protected optimum of the cutting force. The conforming experiments results gave 4.63 %< 5.17%. Therefore, the selected parameters as well as their appropriate levels are significant enough to obtain the desired result.

8. RESULTS AND DISCUSSION:

The end milling Experiment has been conducted, ANOVA is carried out using the results of experiments and then the interpretation methods are used to obtain the present contribution of each parameter and optimum levels of each parameter.

1. The percent contribution of each parameter to the variation of cutting force and optimum parameter shown in table
2. The optimum level of various cutting parameters for minimum cutting force of stainless steel are shown in table
3. The predicted range of optimum cutting force is 3.466 %< 4.32 %< 5.173%

9. CONCLUSION:

From the analysis, it is proved that, by improving the quality by improving the quality by Taguchi method of parameter design at the lowest possible cost, it possible to identify the optimum levels of factors effect on the parameter is less. The outcome of this paper is the optimized process parameters of the end milling process which leads to minimum cutting force. The optimized parameter levels are spindle speed=600rpm, feed rate=0.5mm/min, axial depth of cut=1.5mm, radial depth of cut=1.5mm. Also, the experiments give a clear picture of every factors contribution to the variation in the end milling process, and the quality can be improved without additional investment.

10. REFERENCES

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