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"Implementation of Taguchi Method and ANOVA analysis for optimization of machining process"

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ABSTRACT

In present condition in precise component manufacturing organization, quality and cost of product play a vital role. Reduction of cost in mass production can be done by minimization of waste. The higher production rate can be achieved with the help of process parameter optimization. In this paper, the Taguchi method is used to get the optimal value of depth of cut, spindle speed, feed rate. To conduct experiment universal machining center (UMC) was used. The material selected was aluminum (Al) – 6061. From the ANOVA analysis, it was found that the most favorable combination has been established.

KEYWORDS: ANOVA analysis, Taguchi Method, CNC milling, Cutting Parameters, MRR, Aluminum.

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1] INTRODUCTION

The conventional machines are taking higher timing to make one or many components and as well as needs one man for supervision. As a result, the product produced both expensive and qualitative, depending on the expertise of that machine. This is not possible in those competitive climates. The challenging things of current machine industry are mainly focusing on the highest achievable quality in the terms of, higher production rate, the accuracy of the workpiece, surface finish factor, etc. But the main two contradictory criteria are Quality and productivity in all machining operations. To ensure high productivity, the quality level must be compromised. The Surface roughness and the material of metal removal rate (MRR) play an excellent role in more than one area. UMC machine is capable of achieving the desired milling operation by higher accuracy and as well as having very low process timing. The CNC machine is many mathematical models described by some researchers have been formulated based on statistical regression for proper selection of cutting parameters and cutting performance in milling operations. This method is used for the new approach to finding out the best cutting parameters more competently. This research has selected three main parameters including rate of feed, speed of cutting and deepness of cut for the optimize the MRR during milling processes, which further can be assess by the cost of the manufactured product, productivity or some other criterion [1, 2, 3, 4].

2] LITERATURE REVIEW

Following literature is related to defined problem.

1] The Taguchi design of experiment can be used efficiently in the cumulation of machining specification in the turning process. The significant factors concluded that the effect of feed rate as well as cutting speed is more on the quality characteristic. The depth of the cut parameter has more effect on the machining process that led to maximum surface roughness followed by cutting speed. The analysis has demonstrated that Taguchi parameter design can, fortunately, justify the optimum cutting specification. This experiment has been carried out for the smaller better Taguchi approach. After analysis, it results to know about LM4 machining characteristics and its scope in the industries. (Ankit Kumar Saxena, et. Al [5])

2] The Surface roughness is mainly affected by feed rate, depth off cut and spindle speed. If feed rate value will be increased then the surface roughness value is also increasing, as the value of depth of cut increases the value of roughness is firstly increased then after it will decrease and as the value of spindle speed increased thus the value of surface roughness is decreased. From ANOVA analysis, the new result that effect of this paramere is not affected as surface roughness value effect. The optimal value of the machining parameters is determined for the minimum surface roughness. The value of percentage error in those both experimental results as well as in predictable result is 6.83%. (Narendra Kumar Verma [6])

3] A machine device dynamometer is a multi-part dynamometer that is used to gauge powers amid the utilization of the machine apparatus. With the advancement of innovation, machine device dynamometers are progressively utilized for accurate measurement of powers and for enhancement of the machining procedure parameters. The target of this paper is to represent the methodology embraced in using Taguchi Method to a machine turning task. The profundity of cut, Spindle speed, Feed rate, and Tool Material was utilized as the procedure parameters whereas the Cutting power, Feed power, and Thrust drive are chosen as execution characteristics. The level of influence of each procedure parameter on individual performance trademark was broke down from the exploratory outcomes obtained using Taguchi Method with the assistance of Minitab programming. (Mathiselvan G et. Al.) [7])

4] Taguchi Method is a measurable way to deal with streamline the procedure parameters and improve the nature of parts that are fabricated. The goal of this investigation is to represent the system received in utilizing the Taguchi Method to a machine confronting task. The symmetrical cluster, motion to-clamor proportion, and the investigation of fluctuation are utilized to consider the execution qualities on confronting task. In this examination, three factors in particular speed; feed and profundity of cut were considered. Appropriately, a reasonable symmetrical exhibit was chosen and tests were led. In the wake of directing the trials the surface harshness was estimated and Signal to Noise proportion was determined. With the assistance of charts, ideal parameter esteems were gotten and the affirmation tests were done. These outcomes were contrasted and the consequences of full factorial strategy. (Srinivas Athreya et Al.[8])

5] Plan of Experiment (DOE) is one of the widely utilized strategies for test investigation of many assembling forms in the building. DOE is a factual methodology in which a numerical model is created through exploratory runs. Hence, conceivable yield can be anticipated dependent on the information parameters of the trial setup. The present examination audits current writing on DOE procedures that have been utilized for different welding forms with specific accentuation on the utilization of Taguchi technique on combination circular segment welding forms to be specific, gas tungsten curve welding and plasma bend welding. (S. P. Kondapalli et. Al.) [9])

6] In this paper the cutting of Inconel 718 material utilizing machine by Taguchi approaches. Taguchi advancement approach is connected to advance cutting parameters in turning Inconel 718 material with carbide tipped instrument under dry conditions. The machine is utilized to lead tests dependent on the Taguchi structure of investigations (DOE) with symmetrical (L9) exhibit. The symmetrical cluster flag to commotion proportion (S/N) and examination of fluctuation was utilized to locate the base surface unpleasantness. Ideal outcomes are at long last confirmed with the assistance of compliance tests. (J.Chandrasheker) [10])

7] The improvement of surface unpleasantness in the turning of AISI 1045 was explored by utilizing parameters as cutting rate, feed rate, and profundity of cut. These parameters are most in charge of surface harshness and their working extent is set. Taguchi technique is utilized to gather the exploratory information. Asymmetrical plan L-9, a flag to clamor proportion and investigation of fluctuation were utilized to improve surface unpleasantness. Feed rate applied the higher impact on surface harshness, observed by the profundity of cut. The surface harshness increments with expanding feed rate, the profundity of cut and reduction with diminishing cutting velocity. (Mohammed Irfaan et. Al.) [11])

3] PROBLEM DEFINITION AND OBJECTIVES

- ***Problem definition***

  Process improvements through gradual reduction in the production time by a minimum of 10-20%

- ***Objectives***

1. At the corporate level, the goal is to improving customer satisfaction by meeting their demands without adjusting quality.
2. To reduce waste.
3. Optimize the use of the technique.
4. Uses of the method of design of experiment.

4] METHODOLOGY

Taguchi method has been used for a parameter design including these following steps:

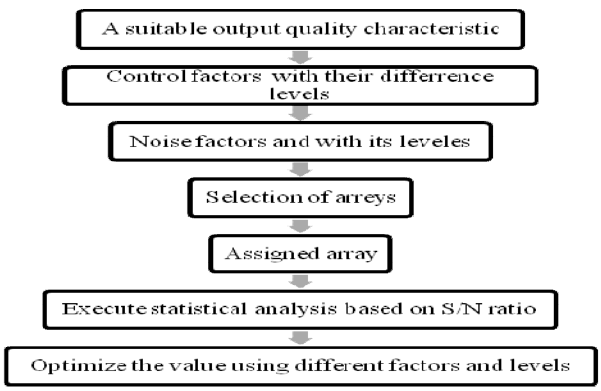

Figure 1 Steps in the Taguchi Method

4.1 Performance Characteristic

Fundamentally, the performance characteristic in the analysis has been divided into main three categories, namely 1) The nominal - the - better, 2) The smaller - the - better and 3) The higher - the - better. According to S/N analysis, the S/N ratio has been calculated for individual level of operation criterions. Moreover, the statistical analysis of ANOVA is defined to recognize process parameter which is more remarkable. Taguchi method is also used for regulating the deviation caused by the intractable factors, which are not included in the conventional design of experiment. The number of controllable milling parameters during the experiment is based on the orthogonal array, which evaluates the data and finally identifies the optimal condition. S/N ratio described as a preferred signal ratio for the unwanted random noise. A large rate of S/N ratio means the signal is enough superior to the unplanned reaction of noise aspect. The three divisions of quality tendency during the analysis of S/N ratio are [12, 13]:

1. Nominal – the – better (NB): The value is more appropriate when it's near to target.
2. Lower – the – better (LB): The predicted value includes some defects such as unwanted allowances, turbulence diameter, etc.
3. Higher – the – better (HB): In this aspect, the output will be desire as having a higher bond of two material strength, the value of material removal, etc.

In Taguchi method, an orthogonal array has been designed to compute the main parameters placed at different rows influence on the result and synergy effects through the merest numbers of experimental trials. From the above categories the larger – to – the – better is used for the calculation of the S/ N ratio for mainly material removal rate as according to the below equation:

$$\frac{S}{N} = -10\ log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y}\,^{2}\right) \qquad (1)\ [14]$$

Here, n is no. of trail value during the experiment.

4.2 Details Of Experiment

Here are the experimental details of the given experiments. The material removal rate shows a meaningful role during the milling operation. The productivity of a product can be increased by increasing material removel rate (MRR).

Table 1: Practical Details

Details	Variable	Constants
Machine used: UMC 750 Work-piece material: Al 6061 The density of material: 2700.00 kg/m^3 Workpiece Dia: 30 mm Hardness: 23.1 HRC	Speed (RPM) Feed (mm / min) Depth of cut (mm)	Workpiece: Al Cutting condition CNC machine Cutting tool material

4.3 Selection Based on the Cutting Parameters and Their Levels

The milling experiment has been done on steel material on the UMC 750 machine. The initial cutting parameters have been taken in an experiment as 1000 RPM cutting speed, 150 mm/min feed and 0.5 mm depth of cut. The parameters and their levels of this experiment are displayed in Table 2.

Table 2: Cutting Parameters with there levels

Details of parameter	Indication	Unit	Level I	Level II	Level III
Feed rate	A	(mm / min)	150	200	250
Depth offcut	B	(RPM)	0.5	1.0	1.5
Cutting speed	C	(mm)	1000	1500	2000

4.4 Orthogonal Array Experiment

The degree of freedom can be formalized by measuring between the process parameters to be completed to find out which level is better from others and how much it is. For example, consider that the 3-level process paramere having two degrees of freedom. So the combination of the two process parameter is to be interacted and regulated by the multification of that 2 processes. In this paper, the reciprocal action between two process parameters has been undervalued. After we get a degree of freedom and our next step would be the selection of perfect orthogonal for the perfect task. Normally, the value of degrees of freedom is always more than process parameter and it may be more than that value. In this, an L9 orthogonal array has been used to handle this three process parameter having six degrees of freedom (DOF = 3 × (3-1) = 6). The column is a cutting parameter, so the available value of the cutting parameter is 9. So, Using L9 orthogonal array we get will study only 9 practical [15, 16].

4.5 Analysis Of The Signal-To-Noise (S/N) Ratio

The S/N ratio is called the ratio of mean value to value of standard deviation. In Taguchi method, S/N ratio is used for the measurement of quality of the characteristic differing from the desired output. Machining time required to reduce the diameter of aluminum from 30 mm to 27 mm for each experiment has been observed and materials removed has been calculated as 17.58 gm for each experiment. Before making operation and after machining operation, the MRR value could be calculated using the below equation.

MRR= $W_1 – W_2 / T * \rho$ …..……………………………………………………................... (2) [17]

Where, W_1 = weight of initial W.P. (grams)

W_2 = weight of final W.P. (grams)

T = maching time during process (sec)

ρ = density (grams / mm3)

Table 3 shows the experimental results for MRR is calculated using Eq. (2) and of S/N ratio is calculated using MINITAB.

Table 3: Experimental results of MRR and S/N ratio

Ex. No.	Spindle speed (rpm)	Feed rate(mm/min)	Depth of cut (mm)	Cycle time for removing material (sec)	MRR (gm/min)	S / n ratio (DB)
1	1000	150	0.5	310	17.9713	28.0873
2	1000	200	1.0	105	15.8130	26.8932
3	1000	250	1.5	85	19.5321	28.6018
4	1500	150	1.0	143	10.2341	23.1891
5	1500	200	1.5	75	25.3051	30.6062
6	1500	250	0.5	125	12.5132	24.9144
7	2000	150	1.5	155	9.781	22.8007
8	2000	200	0.5	135	13.3011	25.4461
9	2000	250	1.0	165	15.2343	26.6299

The total avg S/N ratio = 26.3521 dB

After calculating S/N ratio, the sum of S/N ratio for cutting speed at different levels I, II, and III could be calculated with help of by adding S/N ratio for given slot 1 – 3, 4 – 6, and 7 – 9. So, all value can be calculated in this similar manner. Then the average S /N ratio for all cutting speed at all levels I, II, and III could be calculated with avg. of S/N ratios for given experiments 1 - 3, 4 - 6, and 7 - 9, which are denoted by MS_1, MS_2, and MS_3. MS_1 is given by [18].

$MS_1 = \frac{1}{3} \sum \frac{s}{n}$ ratio for the first level of speed (rpm) = (26.0873+26.8932+28.6018)/3 = 27.86 dB

Similarly, the MS_2 and MS_3 are calculated and as shown in the below table. MF_1, MF_2, MF_3 and MD_1, MD_2, MD_3 are the ave. of S/N ratio for all factor as shown in the table, for three levels I, II and III. The mean value of S/N ratio for all level of cutting parameters is calculated and presented in Table 4.

Table 4: Mean S/N response table for MRR

Machining Parameters	Symbol	Level I	Level II	Level III	Machining parameter
Cutting speed (RPM)	A	27.86	26.24	24.96	2.64
Feed rate (mm/rev)	B	24.69	27.65	26.72	2.03
Depth of cut (mm)	C	26.15	25.57	27.34	1.19

Figure 2 shows the mean S/N ratio corresponds to each level for MRR. From Table 4 and Figure 2 we found that the highest combination of S/N ratio for highest MRR, MS2 - MF2 - MD2 is the perfect combination, which is the suitable combination levels for the factors in milling operation.

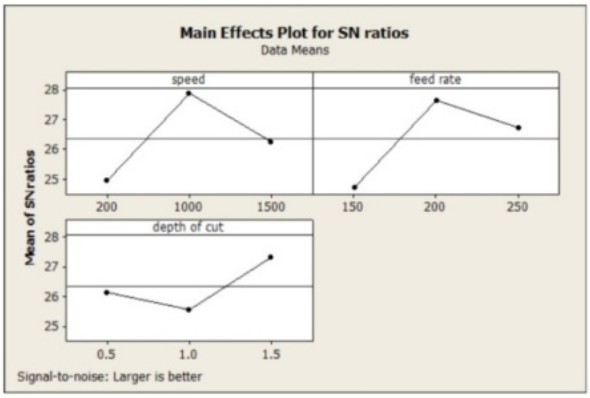

Figure 2: Main effects plot for SN ratio

5] DATA ANALYSIS AND DISCUSSION

The Process can glow by producing higher precisions and lower costing products. To achieve this level, a experiments have been conducted for optimization process, machining performance and surface roughness. S/N ratio has been calculated based on the MRR for each experimental work.

Machining time required to reduce the diameter of steel from 30 mm to 27 mm for each experimental run has been observed and MRR has been calculated. The experimental results can be analyzed by computing the analysis of variance (ANOVA) table.

5.1 Analysis of Variance (Anova) for Mrr

The main purpose of the ANOVA process parameter has more impacts on performance characteristic. Now, the total sum of the squared deviations (SS_T) calculated from equation 3.

$$\eta_m = \frac{1}{9}\sum \frac{S}{N} \text{ ratio} = (26.0873+26.8932+28.6018+23.1891+30.6062+24.9144+22.8007+25.4461+26.3299)/9 = 26.3521 \text{ dB}$$

$$SS_T = \sum_{i=1}^{n} (\eta_i - \eta_m)^2 \ \ldots\ldots (3)$$ [19]

Here, n = number of experiment

η_i = mean of S/N ratio of the experiment

The summation of square deviations of SS_T is divided into two parts: 1) the summation of the square deviations SS_D and 2) the summation of the square (error) SS_E. The degrees of freedom = no. of experiment - 1 = 9 – 1 = 8, and here degree of freedom for each factor = 3 – 1 = 2. Then, F-value for each parameter has been computed by dividing the mean of one square deviation the mean of square error.

$$SS_D = \sum_{j=1}^{k} \eta_j (x_j - \bar{\eta}_m) \quad \text{.........(4)}^{19}$$

$$SS_E = SS_T - SS_S - SS_F - SS_D \quad \text{.........(5)}^{19}$$

Statically, there is a tool name F-test to evaluate which process parameters had a significant role the performance characteristic has been used. F-test can be performed by computing the mean of squared deviations SS_D and then calculating the mean of squared deviation (MS) by dividing SS_D/ degrees of freedom. Then F - value for each can be calculated as SS_D/SS_E. Table 5, Shows the results of ANOVA analysis for MRR. The F-value and % C for feed rate is more in the table, which indicates the feed rate is the most significant contribution to the performance of the machining process.

Table 5: Results of ANOVA for M.R.R.

Affected Factor	SSD	df	ms	f	%c
Speed	39.25	2	19.63	26.14	19.52
Feed	25.62	2	12.82	17.45	8.99
Depth of Cut	55.78	2	27.89	35.92	27.41
Error	1.15	2	0.575		
Total	122.14	8			

From table 3 and 5 it is clear that the optimal value is as bellows 1. Cutting speed: 1500 RPM, 2. Depth of cut: 1.5 mm and 3. Feed 200 mm/min for 2 micron tollerence. and F-test shows that the depth of cut has the most significant factor than cutting speed.

7] RESULT IMPLICATION

This approch is benifical for used in precise manufacturing company products parts which need high tolerence.

8] LIMITATION

The study was done for only three parameters, but it can be more than three parameters such as surface roughness, tolerance, cutting angle, tool position, etc.

9] FUTURE SCOPE

In this study, the Taguchi method was used but another similar method can also be used such as full factorial method.

10] CONCLUSIONS

The paper identified the feasibility of processing on alluminum (Al) 6061 with titanium carbide tool. For this, the Taguchi method and ANOVA analysis to get the optimum value of Metal Removal Rate (MRR) in CNC milling. By, conductive experiment it is found that depth of cut was most segnificant factor compare to feed rate.

Combinations established in this paper are suitable for higher tolerance of 2 micron.

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