PARAMETRIC OPTIMIZATION OF TURNING PROCESS USING TAGUCHI METHOD AND ANOVA ANALYSIS

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ABSTRACT

In the competitive era, quality & cost of a product play vital role to thrive in the global manufacturing environment. The cost of a product can be optimal by mass production and minimize the waste. The higher production rate can be achieved by optimal selections of process parameters during machining of a product by implementing Taguchi method and analysis of variance (ANOVA analysis). The objective of paper is to identify the impacts of process parameters such as cutting speed, feed and depth of cut on material removal rate (MRR) during machining on CNC machine of aluminum material. An orthogonal array of size L_9 has been constructed to find out the optimal levels of the turning parameters and further signal-to-noise (S/N) ratio has been computed to construct ANOVA table. From the ANOVA analysis it has been found that the depth of cut plays most significant factor and feed is least significant factor affecting material removal rate during turning operation of aluminum. The optimal combination of cutting parameters for optimal MRR is depth of cut at 1.5 mm, cutting speed at 1000 RPM and feed at 0.20 mm/rev. The confirmation experiments have conducted to validate the optimal cutting parameters and improvement of MRR from initial conditions is 377.36%.

KEYWORDS: *Taguchi method, CNC Turning, Cutting Parameters, MRR, Aluminum.*

I. INTRODUCTION

Conventional machines are manually controlled by hand wheels or levers. The machines take more time to make one component and needs one man one machine for supervision. This make the manufactured product costly as well as quality of the product vary according to man expertise on that machine, which is not feasible in this competitive environment. The development of manufacturing technologies to improve machining and obtain high productivity has become a very important goal in modern industry. The challenge of modern machining industries is mainly focused on the achievement of high quality, in terms of work piece dimensional accuracy, surface finish, high production rate, less wear on the cutting tools, economy of machining in terms of cost saving and increase the performance of the product with reduced environmental impact. Quality and productivity are two important but contradictory criteria in any machining operations. In order to ensure high productivity, degree of quality is to be compromised. Productivity can be interpreted in terms of material removal rate in the machining operation [1]. Surface roughness and Metal Removal Rate (MRR) plays an important role in many areas and is a factor of great importance in the evaluation of machining parameters. The process parameters like cutting speed, feed rate, depth of cut, coolant condition and tool geometry affects the material removal rate in turning. To achieve the objective of this research, by selecting optimal process parameters for a turning aluminum work piece on EMCO CNC turning machine to get optimal MRR, which finally increase mass production.
The choice of Computerized Numerical Control (CNC) manufacturing process is based on optimization of cost, increased in productivity and improvement of quality of the product by precision manufacturing. CNC machine is capable of achieving the desired turning operation by high accuracy

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The process parameters for surface roughness on aluminum material in pocket machining and observed that surface roughness correlates negatively with cutting speed and positively with feed and depth of cut [7]. Some researchers have studied the influence of process parameters on performance of various aspects of machining like: tool life, tool wear, interaction of cutting forces, surface roughness, material removal rate, machine tool chatter and vibration etc [8, 9]. Some researchers have investigated the machining of nickel based C-263 alloy at high speed using titanium nitride coated carbide inserts. They have found that the significance of feed rate is more than depth of cut in terms of tool performance and its life during machining operation. Taguchi methodology has been used to optimize cutting parameters in CNC turning for surface roughness [10]. The experimental analysis to determine the variation of machining parameters on MRR, gap width and surface roughness has been analyzed and presented in graphical form by Liao [11]. The machining performance in terms of MRR and surface roughness by experimental analysis on ceramics using wire electrical discharge machining has been evaluated [12].

There are two objective of this paper to investigate process parameters for a turning aluminum work piece on EMCO CNC turning machine. The first is to demonstrate a methodical process of using Taguchi parameter design in turning process. The second is to demonstrate the use of Taguchi parameter design in order to find out the optimum MRR with a particular combination of cutting parameters in a turning operation. The statistical analysis techniques have been used to assess the impacts of cutting parameters on MRR. The proper selection of process parameters is essential for getting high cutting performance. The cutting parameters are reflected on MRR, which is used to determine and to evaluate the productivity of a turning product.

The structure of the paper is as follows. Section 2 described in details of methodology used for this research, Taguchi Method has been discussed in section 3, section 4 demonstrated Material Study, Experimental Method has been explained in section 5 followed by discussion of Data analysis and discussions in section 6. Finally, section 7 presents conclusions.

II. METHODOLOGY

The introduction of CNC machine radically changed the manufacturing industry to produce complex curved profile as easy to cut as straight lines and also easy to produce complex 3-D structures. With improved technology like automation of manufacturing processes with CNC machining improved in consistency as well as quality of the product. In CNC turning surface finish and material removal rate are two important factors greatly influence machining performances. CNC machines are considered most suitable in flexible manufacturing system due to its flexibility and versatility as well as capability of achieving reasonable accuracy, surface finish and very low processing time as compared to the conventional machine. Figure 1 shows the block diagram of the working principle of CNC machine.

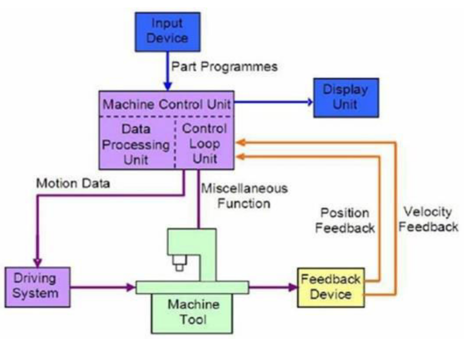

Figure 1. Block diagram of CNC machine

2.1 Turning

Turning is the removal of metal from the outer diameter of a rotating cylindrical work piece to reduce the diameter. Turning is carried on a lathe/CNC that provides the power to turn the work piece at a given rotational speed and to feed to the cutting tool at specified rate and depth of cut. The turning operations are accomplished using a cutting tool; the high forces and temperature during machining create a harsh environment for the cutting tool. Therefore tool life is important to evaluate cutting performance [7]. This paper has considered three cutting parameters: cutting speed, feed and depth of cut for three levels. Due to the studied of three controlling factors for three levels, there are nine experiments were designed and conducted based on Taguchi's L9 orthogonal array.

The experiments were conducted on EMCO CNC turning machine, which is highly versatile and up to date with the latest CNC technology, driven by latest CNC control system. EMCO Concept Turn 250 has a TCM ‘C Axis’ option with 6 driven tools – power 1.2 kw, 200 – 6000 rpm and ‘C’ axis for main spindle, 0-1000 rpm allowing milling operations and simultaneous complex axes cutting work to take place at the same time. The experiments were conducted on standardized shown below Figure 3 the configuration of the machine as listed. Industrial design: 2 axes slant bed lathe, Tool Turret: 12 station VDI automatic tool changer optional 6 driven tool, Max turning diameter: 85 mm, Distance between centre 405 mm, Travel X Z: 100*250 mm, Spindle speed: 60 – 6300 rpm, Max bar stock diameter: 25.5 mm, Feed force: 0-3 N and Display: 12" LCD. Turning of aluminum material on CNC machine has been shown in Figure 2.

Figure 2. Turning Operation on CNC

2.2 Cutting Tool

Cutting tool is device with which a material could be cut to the desired size, shape or finish. For cutting tools, geometry depends mainly on the properties of the tool material and the work material. A single point cutting tool may be either right or left hand cut tool depending on the direction of feed. For single point tools, the most important angles are the rake angles and the end and side relief angles [1, 7]. Figure 3 shows the tools used for the turning operations.

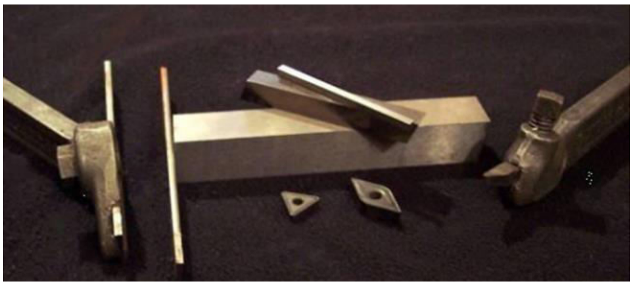

Figure 3. Various Tool Bits, Carbide Inserts and Tool Holders

Speed – Speed refers to the spindle and the work piece rotating speed. For every different diameter on a work piece will have a different cutting speed.
Feed – Feed is the rate at which the tool advances along its cutting path. The feed rate is directly related to the spindle speed and is expressed in mm (of tool advance) per revolution (of the spindle). $F_m = f N\ mm / \min$, where Fm is the feed in mm per minute, f is the feed in mm/rev and N is the spindle speed in RPM.
Depth of cut – Depth of cut is the thickness of the layer being removed (in a single pass) from the work piece or the distance from the uncut surface of the work to the cut surface, expressed in mm.

III. TAGUCHI METHOD

Taguchi method is statistical method developed by Professor Genichi Taguchi of Nippon Telephones and Telegraph Company Japan for the production of robust products. According to Taguchi, total loss generated by a product to the society after shipped is the quality of the manufactured product.. Taguchi has used experimental design as a tool to make products more robust – to make them less sensitive to noise factors. According to Taguchi, by identification of easily controllable factors and their settings the process and product design can be improved. Currently, Taguchi method is applied to many sectors like engineering, biotechnology, marketing and advertising. Taguchi developed a method based on orthogonal array experiments, which reduced "variance" for the experiment with "optimum settings" of control parameters. Hence, the optimal results can be achieved by implementing the combination of Design of Experiments (DOE) with optimization of control parameters. Signal-to-noise (S/N) ratio and orthogonal array are two major tools used in robust design. Signal to noise ratio, which is log functions of desired output measures quality with emphasis on variation, and orthogonal arrays, provide a set of well balanced experiments to accommodate many design factors at the same time [6,14].
The information regarding behavior of a given process can be determined by executing the experiments on it and further collecting data based on the plan of Taguchi method. The collected data from all the experiments have been analyzed and studied the effects of various design parameters. Orthogonal arrays employed by Taguchi method is an important technique for robust design, which allow the effects of several parameters can be determined efficiently with a small number of experiments. The deviation of the experimental value from the desired value can be determined by defining a loss function. The value of loss function is further transformed into a signal-to-noise ratio. Normally, the performance characteristic in the analysis has been divided into three categories, namely, the nominal-the-better, the smaller-the-better, and the higher-the-better. According to S/N analysis, the S/N ratio has been computed for each level of process parameters. Despite of the categories of the performance characteristic, the larger the S/N ratio corresponds to the better performance characteristic for MRR. Further, a statistical analysis of variance (ANOVA) is

performed to identify which process parameters are more significant. S/N ratio is expressed on a decibel scale. Followings are the concept behind the:

- Quadratic Loss Function – used to quantify the loss incurred by the user due to deviation from target performance.
- Signal-to-Noise (S/N) Ratio – used for predicting the field quality through laboratory experiments.
- Orthogonal Arrays (OA) – used for gathering dependable information about control factors with a reduced number of experiments.

Taguchi has been contributed in the area of quality loss functions (QLFs), orthogonal arrays (OAs), robust designs, and Signal-to-Noise (S/N) ratios. Generally, technicians on the shop floor applied this method to improve the products and the processes. The objective function used in the S/N ratio is maximized, which moves design targets toward the middle of the design space for having less effects of the external variation. By doing so a, large reduction in both part and assembly tolerances which are major drivers of manufacturing cost [15].

Taguchi method also allows controlling the deviation caused by the uncontrollable factors, which has not been included at the conventional design of experiment [16]. The number of controllable cutting parameters during the experiment is based on orthogonal array (OA), which analyses the data and finally identify the optimal condition [17]. Taguchi method uses S/N ratio as a response of the experiment, which is a measure of variation when uncontrolled noise factors are present in the system [18]. Noise is the outcome of the quality characteristics of the effect of external factors under test. S/N ratio described as the preferred signal ratio for the undesired random noise value. Taguchi recommends the use of S/N ratio to measure the quality characteristics deviating from the preferred value. The S/N ratio for each level of process parameters has been computed and further determined the highest S/N ratio for the result irrespective of the type of the quality characteristics. A high value of S/N ratio means the signal is much higher than the random effect of noise factors. There are three categories of quality characteristics during analysis of the S/N ratio are given as:

- Nominal-the-Best (NB) – closer to the target value is better, example diameter of a shaft.
- Lower-the-Better (LB) – it predict values pessimistically by including defects like surface roughness, pin holes or unwanted by-product.
- Higher-the-Better (HB) – larger the better characteristics includes the desired output as bond strength, material removal rate, employee participation and customer acceptance rate.

In Taguchi method, an orthogonal array has been designed to compute the main parameters placed at different rows influence on the result and interaction effects through a minimum number of experimental trials [19]. The S/N ratio has been used to measure the performance characteristics of the levels of control factors against these factors. The category the larger-to-the-better was used to calculate S/N ratio for material removal rate according to the equation:

$$S/N = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \quad \ldots(1)$$

Where n is the number of values at each trial and y_i is the each observed value.

In addition, a statistical Analysis of Variance (ANOVA) has been used to determine the significance of the cutting parameters, and also to observe which parameters are significantly affecting the responses. The implementation of conventional experimental design methods are very difficult due to its complicacy and required more number of experiments by increasing the process parameters described by [20]. Taguchi method minimizes the number of experimental trials, by implementing a particular design of orthogonal arrays to study the entire parameter space with small number of experiments. Taguchi Method and ANOVA Approach have applied for the optimization of MRR on steel bar and found that feed rate has most significant factor for highest MRR [21]. The effects of various parameters such as depth of cut, speed and feed on the material removal rate and surface roughness of the SS304 in a CNC turning machine have been investigated and found that the most effecting factors on MRR is depth of cut, on surface roughness is speed and depth of cut, machining time is feed and speed, tool wear is speed and feed [22].The Grey relational based Taguchi method has implemented for optimal Material removal rate and the surface roughness on medium carbon Steel AISI 1045 by using HMT STALLION-100 HS CNC lathe machine [23]. The cutting parameters selection in turning AISI 1045 steel with coated cemented carbide tool under dry cutting condition to find the maximum material removal rate (MRR) and minimum surface roughness. The optimum value of the surface roughness (Ra) is 2.35 µm and the optimum value of the material removal rate (MRR) is 44.15 mm^3 / min [24].

Steps Involved in Taguchi Method

For larger-the-better characteristics, Taguchi method have been used for a parameter design includes the following steps [25]:

1. Select a suitable output quality characteristic to be optimized.
2. Select the control factors and their levels, identify their possible interactions.
3. Select noise factors and their levels.
4. Select sufficient inner and outer arrays. Control factors assigned to inner array and noise factors to the outer array.
5. Carry out the experiment.
6. Execute statistical analysis based on S/N ratio.
7. Predict optimal output performance level based on optimal control factor level combination, and conduct a confirmation experiment to verify the result.

IV. MATERIAL STUDY

Pure aluminum is soft, ductile, and corrosion resistant with high electrical conductivity. It has strength to weight ratio superior to steel. Common alloying elements are copper, zinc, magnesium, silicon, manganese and lithium can be added to improve strength and strain hardening ability of aluminum. The machining parameters such as rotational speed should be less than steel and feed rates are lower on thin walled surface. There are four parameters like cutting force, tool life, surface quality, and chip formation have impact on machinability of a material. Aluminum alloys are classified into two categories: cast alloys and wrought alloys. Most wrought aluminum alloys have excellent machinability compare to cast alloys due to the presence of copper, magnesium and zinc. Machinability of a material depends on the chemical composition of the materials, structural defects and alloying elements. But, with similar chemical composition, the machinability can be improved by heat treatment, which increase hardness, will reduce the built-up edge tendency during machinability. With inclusion of magnesium increase the cutting forces at the same level of hardness. The applications of aluminum alloys used in many areas, like marine, auto parts, aircraft cryogenics, TV towers, transportation equipment, missile components, etc [9].

V. EXPERIMENTAL METHOD

The material removal rate plays an important role during turning operation. The productivity of a product can be increased by increasing MRR [26]. The details of experiments, experimental variables and constants have been shown in the Table 1 and the component design has been shown in the Figure 4.

Table 1. Experimental Details

Details of the Experiment	Experimental Variables	Experimental Constants
Machine used: EMCO CNC Turns 250 machine	Speed Feed Depth of Cut	1.Work Piece : Aluminum 2. Cutting condition 3. CNC machine 4. Cutting Tool Material
Work-piece material: Aluminum Density of material: 2700 kg/m3 Diameter of Work Piece: 40 mm Hardness of Material : 6.8 HRF		
Name of the Tool material: Insert (Titanium Carbide) Shape of Cutting Tool- Triangle		
Cutting Condition: Dry Machining		

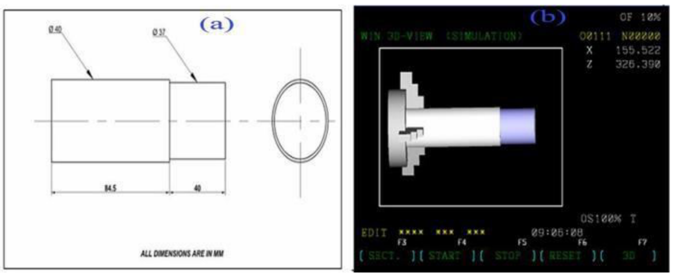

Figure 4. (a) Profile Turning (b) Simulation on machining

The program has prepared for turning operation and has been checked for its accuracy by using a simulation in computer and simulated screen has shown in the Figure 4 (b). Experiments have been designed and carried out using Taguchi's L9 Orthogonal Array.

Selection of cutting parameters and their levels

The cutting experiment has been done on aluminum material on EMCO CNC machine. Cutting speed, depth of cut and feed rate are considered as the control factors. The initial cutting parameters have been taken as cutting speed of 800 RPM, a feed rate of 0.15 mm/rev, and a depth of cut 0.2 mm. The cutting parameters and their levels of this experiment are shown in Table 2.

Table 2. Cutting Parameters and their levels

Process parameters	Symbol	Unit	Level 1	Level 2	Level 3
Cutting speed	A	RPM	600	800	1000
Feed rate	B	mm/rev	0.10	0.15	0.20
Depth of cut	C	mm	0.5	1.0	1.5

Orthogonal array experiment

To find out the suitable orthogonal array for experiments is based on the degrees of freedom. The degrees of freedom can be defined by comparisons between process parameters that required to be completed to find which level is better and how much it is. For example, three-level process parameters have two degrees of freedom. The experimental layout for the cutting parameters has been shown in Table 3.

Table 3. Experimental layout using an L_9 orthogonal array

Experimental No.	Cutting parameter level		
	Cutting Speed (RPM)	Feed Rate (mm/rev)	Depth of cut (mm)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	3
5	2	2	1
6	2	3	2
7	3	1	2
8	3	2	3
9	3	3	1

The degrees of freedom associated with the interaction between two process parameters are determined by the product of the degrees of freedom of two process parameters. In this research, the interaction between two process parameters has been neglected. After getting the degrees of freedom, next step is to select a proper orthogonal array to fit for the task. Normally, the degrees of freedom for the orthogonal array should be greater than or at least equal to those for the process parameters. In this paper, an L_9 orthogonal array has six degrees of freedom (DOF = 3 × (3-1) = 6) has been used to handle 3-level process parameters. Each cutting parameters are assigned to a column, nine cutting parameters are being available. Therefore, only 9 experiments are required to study the entire parameter space using the L_9 orthogonal array.

Analysis of the signal-to-noise (S/N) ratio

In the Taguchi method, the term 'signal' signifies the desired value (mean) for the output characteristic and the term 'noise' signifies the undesirable value (S.D.) for the output characteristic. Therefore, the S/N ratio is the ratio of the mean to the S.D. In Taguchi method, S/N ratio has been used to measure the quality of characteristic deviating from the desired value. As mentioned earlier, there are three categories of performance characteristic, namely, lower-the-better, higher-the-better, and nominal-the-better. To get optimal machining performance, the higher-the-better performance characteristic for MRR has been taken.

Machining time required to reduce the diameter of aluminum from 40 mm to 37 mm for each experiment has been observed and materials removed has been calculated as 19.595 gms for each experiment. Material removal rate (MRR) can be calculated using the difference of weight of work piece before and after the machining operation.

$$MRR = \frac{W_i - W_f}{\rho . t}$$

where, W_i is the initial weight of the work piece in grams, W_f is the final weight of the work piece in grams, ρ is the density of the material in grams / mm^3, and t is the time taken for machining. In practice MRR should be high, thus Taguchi method refers to select the process parameter having more S/N ratio.

Table 4 shows the experimental results for MRR and corresponding S/N ratio using Eq. (1) and the effect of each cutting parameter at different levels.

Table 4. Experimental results for MRR and S/N ratio.

Exp. No.	Control Parameter (Level)			Result / Observed Value				
	Speed (RPM)	**Feed** (mm/rev)	**Depth of Cut** (mm)	**Cutting Speed** (m/min)	**Cycle Time to Remove Material** (sec)	**MRR** (gm/min)	**MRR** (mm^3/min)	**S/N Ratio** (dB)
1	600	0.10	0.5	75.398	300	3.91912	1451.52	63.236
2	600	0.15	1.0	75.398	115	12.6409	4681.819	73.408
3	600	0.2	1.5	75.398	75	17.0384	6310.531	76.001
4	800	0.10	1.0	100.530	133	9.19765	3406.537	70.646
5	800	0.15	1.5	100.530	110	13.06186	4837.728	73.693
6	800	0.2	0.5	100.530	120	8.4855	3142.777	69.946
7	1000	0.10	1.5	125.663	60	19.519	7255.925	77.214
8	1000	0.15	0.5	125.663	120	9.797	3628.518	71.195
9	1000	0.2	1.0	125.663	54	36.2853	13439.026	82.567

The total mean S/N ratio = 73.10 dB

After computing S/N ratio, the sum of S/N ratio for cutting speed at levels 1, 2, and 3 can be calculated by adding the S/N ratio for the experiments 1-3, 4-6, and 7-9. The sum of S/N ratio for each level of the other cutting parameters has been computed in similar manner. Then the average S/N ratio for cutting speed at levels 1, 2, and 3 can be computed by averaging the S/N ratios for the experiments 1-3, 4-6, and 7-9, which is denoted by MS_1, MS_2, and MS_3. MS_1 is given by:

$$MS_1 = \frac{1}{3} \sum S / N \text{ ratio for the first level speed} = \frac{1}{3} (69.23 + 73.41 + 76.01) = 70.88$$

Similarly the MS_2 and MS_3 are calculated and are shown in the table below table. MF_1, MF_2, MF_3 and MD_1, MD_2, MD_3 are the average S/N ratio for feed and depth of cut factor, for three levels 1, 2 and 3. The mean S/N ratio for each level of cutting parameters is calculate and presented in Table 5, called the mean S/N response table for MRR.

Table 5. Response table to identify significance of machining parameter for MRR

Machining Parameters	Symbol	Mean S/N Ratio (dB)			Machining Parameter (Max-Min)
		Level 1	Level 2	Level 3	
Cutting speed (RPM)	A	70.88	71.42	76.99 *	6.11
Feed rate (mm/rev)	B	70.36	72.76	76.17 *	5.81
Depth of cut (mm)	C	68.12	75.54	75.63 *	7.51

Figure 5 show the mean S/N ratio corresponds to each level for MRR. From Table 5 and Graph 1, all level totals are compared and combination yielding the highest combined S/N ratio is selected for maximum metal removal rate. In this experiment, S3-F3-D3 combination yields the maximum metal removal rate. This is the optimal levels combination of factors for turning operation in CNC for aluminum material.

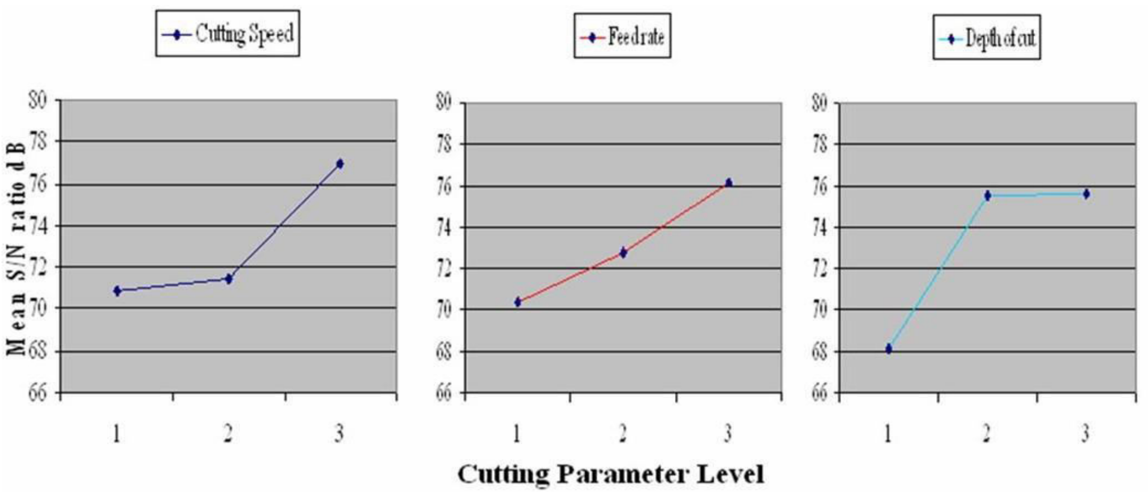

Figure 5. S/N ratio graph for MRR

VI. DATA ANALYSIS AND DISCUSSION

Due to competitive environment, a company can thrive by producing high precision and low cost products. To achieve this, a lot of research has been conducted on optimization, machining performance and surface roughness forecast. The analysis of the impact of cutting parameters on MRR is very important in terms of the improving the productivity of the component. S/N ratio has been computed based on the MRR for each experiment. It has observed that S/N ratio under optimum conditions differ from the predictive prediction and can be estimated from machining results under optimum conditions. In practice MRR should be high, thus Taguchi method refers to select the process parameter having more S/N ratio.

Machining time required to reduce the diameter of aluminum from 40 mm to 37 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.

Analysis of Variance (ANOVA) for MRR

The purpose of the ANOVA is to investigate which process parameter has more impacts on performance characteristic. This is achieved by minimizing the effect of signal-to-noise ratio, which is calculated by the sum of squared deviations from the total mean of the multi response signal-to-noise ratio, into contributions by each of the process parameters and the error. First the total sum of the squared deviations (SS_T) from the total mean (η_m) of the S/N ratio can be calculated as:

$$\eta_m = \frac{1}{9}\sum sum\ of\ all\ the\ S/N\ ratio = \frac{1}{9}[63.24+73.41+76.00+70.65+73.69+69.95+77.21+71.19+82.57] = 73.10\ dB$$

$$SS_T = \sum_{i=1}^{n}(\eta_i - \eta_m)^2$$

where, n is the number of experiments in the orthogonal array and η_i is the mean S/N ratio for the ith experiment.

The total sum of the squared deviations SS_T is decomposed into two sources: the sum of the squared deviations SS_D due to each process parameters and the sum of the squared error SS_E. Then mean square (MS) is calculated by dividing the degrees of freedom of a factor to the sum of squares due to each factor. The 'effects of factor level' is defined as the deviation it causes from the overall mean. The total degrees of freedom = number of experiments-1 = 9-1=8, where as degrees of freedom for each factor = 3-1=2. Then, F-value for each parameter has been computed by dividing the mean of square deviations the mean of square error. The percentage contribution (%C) by each of the process parameter in the total sum of the squared deviations SS_T can be used to evaluate the importance of the process parameter change on the quality characteristic.

$$SS_D = \sum_{j=1}^{k} n_j (\bar{x}_j - \eta_m)$$

$$SS_E = SS_T - SS_S - SS_F - SS_D$$

Statically, there is a tool name F-test to evaluate which process parameters have a significant role the performance characteristic has been used as Taguchi method cannot determine the effects of individual parameters on entire process [27]. F-test can be performed by computing the mean of squared deviations SS_D and then calculating mean of squared deviation (MS) by dividing SS_D/degrees of freedom associated with the process parameter. Then F-value for each process parameter can be calculated as SS_D/SS_E. Normally, larger the F-value more effects on performance characteristic due. Al last, percentage contribution of individual parameters can be determined using ANOVA analysis. Table 6 shows the results of ANOVA analysis for MRR. The F-value and % C for feed rate is more in the table, which indicates that feed rate is significantly contributing towards machining performance than cutting speed and depth of cut.

Table 6. Results of the analysis of variance for MRR

Factor	SS_D	DF	MS	F	%C
Speed	68.58	2	34.28	46.01	29.51
Feed	50.97	2	25.48	34.20	21.94
Depth of Cut	111.29	2	55.64	74.68	47.91
Error	1.49	2	0.745		
Total	232.31	8			

Therefore, based on S/N ratio and ANOVA analysis for MRR, the optimal cutting parameters for material removal rate has been found from Table 2 at level 3 as cutting speed 800 RPM in level 3, feed 0.20 mm/rev in level 3 and depth of cut 1.5 mm in level 3. From above analysis, paper concludes that the factor feed rate has the most significant factor and its contribution to material removal rate is more. The next significant factor is cutting speed and least significant factor is depth of cut.

Taguchi method cannot determine the effects of individual parameters on entire process while percentage contribution of individual parameters can be determined using ANOVA. It can be employed to investigate effect of process parameters speed, feed and depth of cut. The percentage contribution of parameters indicates that depth of cut is significantly contributing towards machining performance. From this analysis, we come across that the factor depth of cut has the most significant factor for optimal MRR. The next significant factor is speed and then significant factor is feed. The purpose of the ANOVA was to identify the important parameters in prediction of Material removal rate.

Confirmation Tests

After selecting the optimum level of process parameters, the final step is to predict and verify the improvement in performance characteristic by using the optimum level cutting parameters. The estimated S/N ratio $\eta_{predicted}$ using the optimal level of the process parameters can be computed as [2]

$$\eta_{predicted} = \eta_m + \sum_{i=1}^{o} (\eta_i - \eta_m) \qquad ...(2)$$

where η_m is the total mean of the S/N ratio, η_i is the mean S/N ratio at the optimal level, and o is the number of main process parameters that affect the performance characteristic. The estimated S/N ratio using the optimal cutting parameters for MRR has been obtained and the corresponding MRR can be calculated by using Eq. (1). Table 8 shows the comparison between predicted MRR with the actual MRR using optimal cutting parameter. The increase of the S/N ratio from the initial cutting parameter to the optimal cutting parameter is 11.53 dB, which means that MRR is increased by about 3.77 times. Therefore, prior design and analysis for optimizing the cutting parameters required for optimum MRR.

Table 8. Results of conformation test for MRR

	Initial Cutting Parameter	**Optimal Cutting Parameter**	
		Predicted	**Experiment**
Level	A2B2C1	A3B3C3	A3B3C3
MRR (mm^3/min)	3628.7		13693.22
S/N ratio (dB)	71.20	82.59	82.73
Improvement of S/N ratio = 11.53 dB			

VII. Conclusions

The paper has studied the feasibility of turning aluminum by titanium carbide tool. Taguchi method and ANOVA analysis has been implemented to find out the optimal levels of cutting parameters like cutting speed, feed rate and depth of cut to achieve the optimum value of MRR in CNC turning of aluminum. The L_9 orthogonal array has been constructed for experimental planning and analysis of MRR. The experimental results based on S/N ratio approach and ANOVA analysis provides a systematic and efficient methodology for the optimization of cutting parameters for MRR. The results based on F-test shows that depth of cut has most significant factor than cutting speed is significant and feed has least significant impacts on MRR of aluminum turning. The optimal combination of cutting parameters for optimal MRR is depth of cut at 1.5 mm, cutting speed at 1000 RPM and feed at 0.20 mm/rev. The confirmation experiments have been conducted to validate the optimal cutting parameters. The improvement of MRR from initial cutting parameters to the optimal cutting parameters is around 377.36%.

7.1 Scope for Future Work

In this research, three parameters have been studied in accordance with their effects for maximum MRR. Other parameters like nose radius, types of Inserts, power consumption can be studied further. In the same way, by considering above parameters optimal surface roughness can be determined by considering the quality of product.

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