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EXPERIMENTAL INVESTIGATION OF CNC TURNING OF ALUMINUM USING TAGUCHI METHOD

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Abstract - ***The objective of this research is to utilize Taguchi methods to optimize the material removal rate for machining operation and the effects of CNC machining processes on aluminum samples. There are three important cutting parameters namely, cutting speed, feed rates and depth of cut, which has been considered during the machining of Aluminum alloy. This research examines the effects of process parameters on Material Removal Rate (MRR) during machining on CNC. An Orthogonal array has been selected and constructed to find the optimal levels and to analyze the effect of the turning parameters. The signal-to-noise (S/N) ratio has been calculated to construct the analysis of variance (ANOVA) table to study the performance characteristics in dry turning operations. ANOVA has shown that depth of cut has significant role in producing higher MRR. The optimal results have been verified through conformation experiments with minimum number of trials as compared with full factorial design. The best cutting parameters for material removal rate has been found as cutting speed 1000 RPM, feed 0.20 mm/rev and depth of cut 1.5 mm on the basis of ANOVA analysis.***

Key Words: *Taguchi method, CNC Turning, Cutting Parameters, ANOVA, MRR.*

1. INTRODUCTION

In today's competitive and dynamic market environment, manufacturing industries have frequently assigned a high priority to economic machining under complex machining conditions for the optimization of production activities. Manufacturing the high quality product with increasing productivity are the main concern of metal-based industries. The high speed machining (HSM) and modern machining technologies are being used to machine the parts that need significant amount of material removal. Rao [1] describes turning as one of the most important machining process in which a single point cutting tool removes unwanted material from the surface of a rotating cylindrical work piece. The process parameters like cutting speed, feed rate, depth of cut, coolant condition and tool geometry affects the material removal rate in turning. The proper selection of process parameters is essential to optimize the metal removal rate. The present study proposes application of Taguchi method to optimize the CNC turning operation for maximum material removal rate. The objective of this paper is to investigate process parameters for a turning aluminum work piece on EMCO CNC turning machine. In this study, three levels of speed, feed and depth of cut are evaluated for high material removal rate (MRR).

The choice of CNC manufacturing process is based on cost optimization, improvement of productivity and quality of the product by precision manufacturing. In manufacturing industries after optimal selection of cutting conditions and cutting tools, experienced shop-floor machine tool operators play a vital role in producing high quality product and improving the productivity of the products. From last few decades, it has been observed that selecting and implementing optimal machining conditions and most suitable cutting tool during machining operations. There are many cutting parameters like cutting speed, feed rate and depth of cut has been selected to optimize the economics of machining operations, as assessed by productivity, total manufacturing cost per part or some other criterion. Regardless of early works on setting up optimum cutting speeds in Computerized Numerical Controlled (CNC) machining, the recent research (Sanjit et al., 2010; Kadirgama et al., 2008; Basim et al., 2010) have detailed that the process parameters need to be optimized as CNC machining is an essential and costly process for small and medium type manufacturing industries [2 – 4]. Yang and Tarng, 1998, analyzed the cutting parameters based on the cutting characteristics of S45C steel using Taguchi method and ANOVA analysis for determination of optimal cutting parameters [5]. Gopalsamy et al., 2009 described the parameter optimization of machining hardened steel. The common tendency of process is to reduce the machining cost and time and increasing the accuracy of the product. By considering this problem, this paper uses Taguchi Method develop a machining technique with higher cutting speed, feed rate and depth of cut with better surface finish [6, 7].

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, quality of a manufactured product is total loss generated by that product to society from the time it is shipped. Taguchi stresses the importance of designing quality into product into processes, rather than depending on the more traditional tools of on-line quality control. Dr. Taguchi uses experimental design as a tool to make products more robust – to make them less sensitive to noise factors. Taguchi improves the process and product design by identification of easily controllable factors and their settings, which minimizes the variation in product response while keeping the mean response on target. By setting those factors at their optimal levels, the product can be made robust to changes in operating and environmental conditions. Thus, more stable and higher-quality products can be obtained by Taguchi's Method. 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. Thus the combination of Design of Experiments (DOE) with optimization of control parameters to obtain best results is achieved in the Taguchi Method. Signal to noise (S/N), ratio and orthogonal array are two major tools used in robust design. Signal to noise ratio, which are 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 simultaneously presented [7, 8].

Taguchi's robust design method is suitable to analyze the metal cutting problem by considering the optimization in end milling using S/N ratio approach and Pareto ANOVA method. Ghani et al., 2004 [9] established that the conceptual S/N ratio and Pareto ANOVA approaches for data analysis in end milling uses at high cutting speed of 355 m/min, low feed rate of 0.1mm per tooth and low depth of cut of 0.5 mm. Application of Taguchi's method for parametric design was carried out to determine an ideal feed rate and desired force combination Although small interactions exist between a horizontal feed rate and desired force, the experimental results showed that surface roughness decreases with a slower feed rate and larger grinding force, respectively presented [10]. Feng, 2001 and Thamizhmanii, 2007 have been considered the impact of turning parameters on surface roughness. They considered that the surface roughness of work material depends on work material, nose radius of tool, feed, speed and depth of cut. They found that the feed have most significant impact on the observed surface roughness and also observed that there were strong interactions among different turning parameters [11, 12]. Jafar and Afsari, 2010 has demonstrated the performance characteristics in turning operations of Df2 (1.2510) steel bars using TiN coated tools. Three cutting parameters namely, cutting speed, feed rate, and depth of cut, will be optimized with considerations of surface roughness [13]. Pramod et al., 2006 demonstrated a systematic procedure of using Taguchi technique for optimizing the MRR in Electric Discharge Machine (EDM) [14]. Thamizhmanii, 2007 has applied Taguchi methodology to optimize cutting parameters in CNC turning for surface roughness. This paper depicts the turning of aluminum with parameters with parameters of turning at three levels and four factors each. The main objective of the paper is to find the turning parameters to achieve the optimal material removal rate [12].

The rest of the paper has been arranged like in section 2, Methodology of the experiment has been stated. Taguchi Method has been presented in section 3. Material Study for this research is described in section 4. In section 5, Experimental Set up and Cutting Conditions has been detailed demonstrated followed by Results and Discussion in section 6. Finally, section 7 presents conclusions.

2. METHODOLOGY

There are various methodologies by which CNC machining operation can be optimized to improve the quality of a product or process. Some of the widely used approaches in product\process development are:

1. Build-test-fix
2. One-factor-at-a-time (the classical approach)
3. Design of experiments (DOE)

The "Build-test-fix" is the primal approach to conduct the process according to the resources available, rather than optimize it. On the other hand, the objective of "One-factor-at-a-time" approach is to optimize the process by running an experiment at one particular condition and repeating the same experiment by changing one factor till the effect of all the factors are known.

2.1 Design of Experiments

The Design of Experiments (DOE) is the most powerful statistical technique in product\process development. The general quantitative approach which is more logical has been selected for designing the experiments to achieve a predictive knowledge of a complex, multi-variable process with the fewest trials possible. In this research, a 3 factor three level factorial technique has been employed for the development of design matrix to conduct the experiments. Following are the major approaches in DOE:

- Factorial Design
- Taguchi Method (Fractional Factorial Design)

A full factorial experiment is an experiment whose design consists of two or more factors, each with discrete possible values or "levels", and whose experimental units take on all possible combinations of these levels across all such factors. A full factorial design may also be called a fully crossed design. Such an experiment allows studying the effect of each factor on the response variable, as well as the effects of interactions between factors on the response variable. A common experimental design is one with all input factors set at two levels each. If there are k factors, each at 2 levels; a full factorial design has 2^k runs.

3. TAGUCHI METHOD

In Taguchi method, the main parameters have influence on process results, which are positioned at different rows in a designed orthogonal array. The difference between the functional value and objective value is recognized as the loss function that can be expressed by signal-to-noise (S/N) ratio has been demonstrated by Kaladhari and Subbaiah [15]. The category the larger-to-the-better was used to calculate S/N ratio for material removal rate according to the equation:

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

In addition, a statistical Analysis of Variance (ANOVA) has been performed to observe which parameters are significantly affecting the responses. Traditional experimental design methods are very complicated and difficult to implement, as it require a large number of experiments by increasing the process parameters demonstrated by Lan et al., [16]. To minimize the number of tests, Taguchi experimental design has developed by Taguchi to implement a particular design of orthogonal arrays to study the entire parameter space with small number of experiments.

3.1 Product / Process Diagram

A Product / Process diagram is used to designate the different factors influences of a product/process. The figure 1 shows the various influencing factors of product/process design.

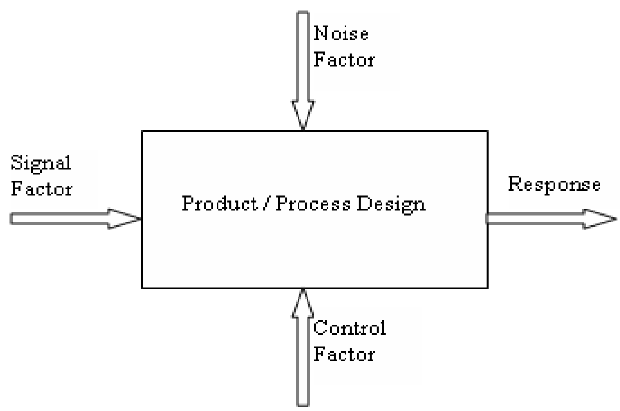

Fig -1: Product/process diagram

The signal factor, like product design or sequence of process is the input into the Product/Process design. The control factors are the factors, which can be controlled to obtain the desired output, like speed, cutter radius, etc. The noise factors are the uncontrollable factors, like temperature, humidity, vibration, friction, etc for the deviation of the output from the desired output. Response is the outcome of the Product/Process after giving three input variables.

3.2 Steps Involved in Taguchi Method

Taguchi method used the parameter design to optimize a process with multiple performance characteristics includes the following steps:

1. Identify the main function and side effects.
2. Identify the noise factors, testing condition and quality characteristics.
3. Identify the objective function to be optimized.
4. Identify the control factors and their levels.
5. Select the orthogonal array for experimentation and obtain the Matrix.
6. Conduct the Matrix experiment.
7. Examine the data, predict the optimum control factor levels and performance.
8. Conduct the verification experiment.

4. MATERIAL STUDY

Aluminum is derived from bauxite using Bayer process to alumina and then converted to aluminum using electrolytic cells. Pure aluminum is soft, ductile, and corrosion resistant and has a high electrical conductivity. It has strength to weight ratio superior to steel. Aluminum is commonly alloyed with copper, zinc, magnesium, silicon, manganese and lithium to improve strength and strain hardening ability. Traditional machining operations like turning, milling, boring, tapping, etc are easily performed on aluminum and its alloys. However, some machining parameters such as rotational speed should be less than steel and feed rates are lower on thin walled surface. Normally, higher speeds, feeds and depth of cut may be employed in many applications depending on the nature of the parts, machine tool, tool design, lubrication and other cutting conditions. Jorstad 1980, described the formation of chips with their length and curl, as well as the ease or difficulty associated with their removal and handling, influence of surface finish [17].

Machinability is the degree of difficulty that a material creates when being machined. There are four parameters like cutting force, tool life, surface quality, and chip formation have impact on machinability of a material. Machinability of aluminum alloys depends on the type of alloy added to it. Machinability of pure aluminum is difficult in compare to aluminum alloys. Aluminum requires approximately 30 % of the cutting force necessary for steel materials. During machining of aluminum alloys by giving low cutting force, it is possible to achieved good dimensional accuracy and outstanding tool life. Tooling can range from high speed steel to carbide inserts depending on the alloy being machined Diamond tooling is used for best surface finish.

Aluminum alloys are classified into two categories: cast alloys and wrought alloys. Most wrought aluminum alloys have excellent machinability where as cast alloys, which contains copper, magnesium, and zinc as the main alloying elements causes machining difficulties. Tash et al., 2006, has investigated the effect of metallurgical parameters on the drilling performance of heat treated aluminum alloy at fixed machining conditions. Machinability of a material depends on the chemical composition of the materials, structural defects and alloying elements [18]. 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 has been demonstrated by Tash et al., [18]. Alloys having silicon as main alloying element involve larger tool rake angles, lower speed and feed, more cost-effective machining process. The applications of aluminum alloy used in many areas, like marine, auto parts, aircraft cryogenics, TV towers, transportation equipments, missile components, etc.

5. EXPERIMENTAL SET-UP AND CUTTING CONDITIONS

Mustafa and Ali analyzed the effect of the length and diameter of work piece during machining operations, while keeping the cutting speed constant [19, 20]. The material removal rate (MRR) plays an important characteristic in turning operation and according to Gaitonde, et al. [21], high MRR is always desirable for increasing the productivity. In this paper, there are three cutting parameters: cutting speed, feed rate and depth of cut are considered for three levels. Three variables are studied for three levels and hence nine experiments were designed and conducted based on Taguchi's L9 orthogonal array. The details of experiments, experimental variables and constants have been shown in the Table 1.

Table -1: Experimental details

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Details of the Experiment	Experimental Variables	Experimental Constants
Machine used: EMCO CNC Turns 250 machine	Speed Feed Depth of Cut	Work Piece : Aluminium Cutting condition CNC machine Cutting Tool material
Work-piece material: Aluminium Density of material: 2700 kg/m3 Diameter of Work Piece: 40 mm Hardness of Material : 6.8 HRF (applied load = 60 kg.f with steel ball indenter)		
Name of the Tool material: Insert (Titanium Carbide) Shape of Cutting Tool- Triangle		
Process parameters: Speed, Feed and Depth of cut		
Cutting Condition: Dry Machining		

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 2 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.

Fig-2: EMCO Concept Turn 250

5.1 Identifying control factors

Cutting speed, depth of cut and feed rate are considered as the control factors. The cutting parameters and their levels of this experiment are shown in Table 2.

Table-2: Cutting Parameters and their levels

Process parameters	Level 1	Level 2	Level 3	Mean of parameters
Cutting Speed(RPM)	600	800	1000	800
Feed (mm/rev)	0.10	0.15	0.20	0.15
Depth of Cut(mm)	0.5	1.0	1.5	1.0

5.2 Experimental Plan and Experimentation

The component has drawn in AutoCAD 11 and shown in the Figure 3. 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. Experiments have been designed and carried out using Taguchi's L9 Orthogonal Array (OA).

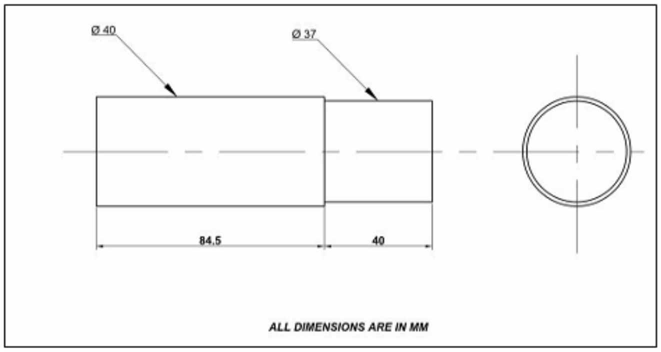


Fig -3: Profile Turning

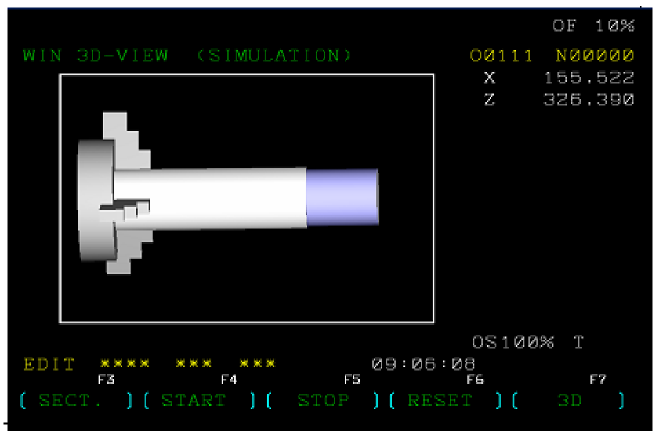


Fig -4: Simulation of machining

In this research, a 3 factor three level factorial technique has been implemented for the development of design matrix to conduct the experiments, refers in Table 3 to represent the orthogonal array for our experiment. The objective of this research to obtain a mathematical model that relates the material removal rate to three cutting parameters in CNC turning process. The objective of using the S/N ratio as a performance measurement is to develop products and process insensitive to noise factor. The sample calculations for the first experiment are shown below. The experimental values of MRR and S/N ratios are tabulated in the Table 3.

Table -3. L_9 Table and Experimental Values with calculations

Exp. No.	**Control Parameter (Level)**			**Result / Observed Value**					
	Speed	**Feed**	**Depth of Cut**	**Cutting Speed (m/min)**	**Weight of Material Removed (gms)**	**Cycle Time to Remove Material (sec)**	**MRR (gm/min)**	**MRR (mm^3/min)**	**S/N Ratio**
1	600	0.10	0.5	75.398	19.5956	300	3.91912	1451.52	63.236
2	600	0.15	1.0	75.398	19.5934	115	12.6409	4681.819	73.408
3	600	0.2	1.5	75.398	19.5942	75	17.0384	6310.531	76.001
4	800	0.10	1.0	100.530	19.591	133	9.19765	3406.537	70.646
5	800	0.15	1.5	100.530	19.5928	110	13.06186	4837.728	73.693
6	800	0.2	0.5	100.530	16.1971	120	8.4855	3142.777	69.946
7	1000	0.10	1.5	125.663	19.591	60	19.519	7255.925	77.214
8	1000	0.15	0.5	125.663	19.594	120	9.797	3628.518	71.195
9	1000	0.2	1.0	125.663	19.5941	54	36.2853	13439.026	82.567

5.3 Sample Calculation of MRR and S/N ratio

The turning operations are carried out as per the L9 Orthogonal Array and weight of the work piece before machining and after machining is measured and tabulated in the Table 3. Cycle time required for machining for each experiment is observed. 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, p is the density of the material in grams / mm3, and t is the time taken for machining.

Metal Removal Rate in gms/minute = Weight of Metal Removed in grams Divided by Cycle time in minutes.

Metal Removal rate in MM^3/minute = Metal Removal rate in Grams/Minute Divided by Density of Work Piece in mm^3/grams.

$$Cutting\ Speed\ (V) = \frac{\pi DN}{1000} = 75.4\ mm/\min \quad ...(5.1)$$

$$Volume\ (v) = \pi r^2 h = 156047.3\ mm^2 \quad ...(5.2)$$

$$Weight\ of\ material\ before\ machining\ (w_1) = v\rho = 156047.3 \times 2.7 \times 10^3 = 421\ gms \quad ...(5.3)$$

$$Weight\ of\ material\ after\ machining\ (w_2) = (v_1 + v_2)\rho =$$

$$where,\ v_1 = \pi \times 18.5^2 \times 40 = 43008.3\ and$$

$$v_2 = \pi \times 20^2 \times 84.2 = 105808.8$$

$$(43008.4 + 105808.8) \times 2.7 \times 10^3 = 401.8\ gms \quad ...(5.4)$$

$$Weight\ of\ materials\ removed\ (w) = w_1 - w_2$$

$$= 421 - 401.8 = 19.6\ gms \quad ...(5.5)$$

$$Starting\ Time\ (t_1) = 14:07:25\ and\ Finishing\ Time\ (t_2) = 14:12:25$$

$$Cycle\ Time\ to\ remove\ the\ material\ (t) = t_1 - t_2 = 5 \min \quad ...(5.6)$$

$$MRR\ \left(\frac{gms}{min}\right) = \frac{w}{t} = \frac{19.6}{5} = 3.92\ gms/\min \quad ...(5.7)$$

$$MRR\ (mm^3) = \frac{MRR\ (gms/min)}{\rho} = \frac{3.92}{2.7 \times 10^{-3}} = 1451.52\ mm^3/\min \quad ...(5.8)$$

$$\frac{S}{N}\ ratio = -10\ log\left[\frac{1}{n} \times \frac{1}{y^2}\right] = -10\ log\left[\frac{1}{1} \times \frac{1}{(1451.52)^2}\right] = 63.2\ db \quad ...(5.9)$$

6. RESULTS AND DISCUSSION

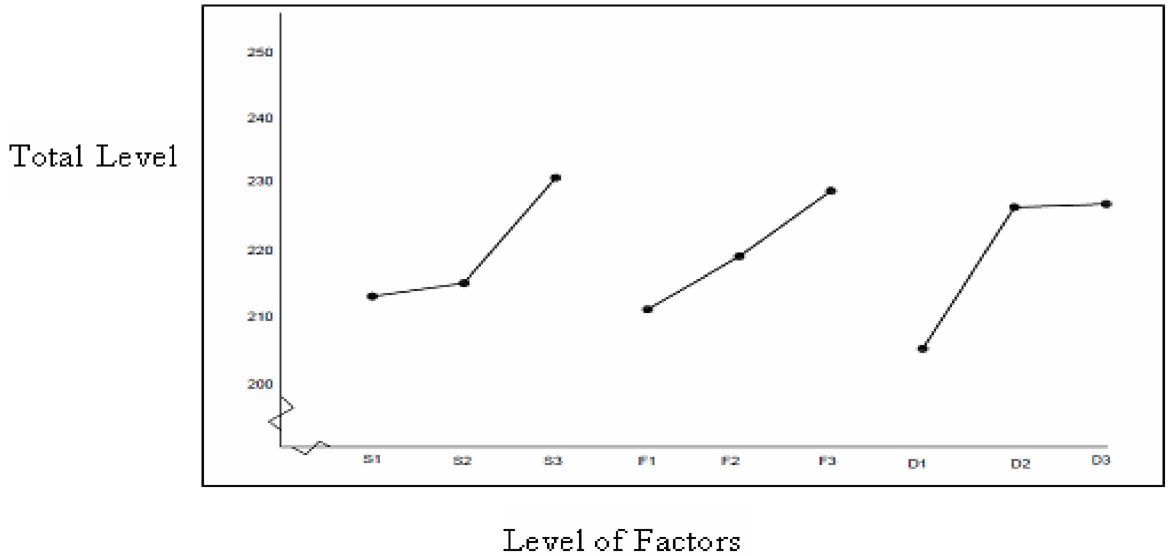
In practice MRR should be high, thus Taguchi method refers to select the process parameter having more S/N ratio.

6.1 Response Table and Diagram for MRR

The response table, which contains the sums of the S/N ratios for each level and for each factor is shown in the Table 4

Table-4: Level Totals of S/N ratio for each factor

Factors	Depth of Cut	Feed	Cutting Speed
Level 1	204.377	211.096	212.645
Level 2	226.622	218.295	214.285
Level 3	226.908	228.515	230.976
Difference	22.531	17.419	18.330
Total	657.906	657.906	657.906



Graph-1: Graph of Response Diagram for MRR

From Table 4 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.

6.2 Analysis of Variance (ANOVA) for MRR

The purpose of the ANOVA is to investigate process parameters, which significantly affect the quality characteristic. This is accomplished by separating the total variability of the multi response signal-to-noise ratio, which is measured 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 means (η_m) S/N ratio can be calculated as:

$$\eta_m = \frac{1}{9}\sum sum\ of\ all\ the\ S/N\ ratio$$

$$\eta_m = \frac{1}{9}\begin{bmatrix} 63.236 + 73.408 + 76.001 + 70.646 + 73.692 \\ +69.946 + 77.213 + 71.194 + 82.567 \end{bmatrix} = 63.92$$

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

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. The percentage contribution 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.

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

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

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 average S/N ratio for these experiments, which is denoted by MS_1, MS_2, MS_3, are the average S/N ratio for speed factor, for three levels 1, 2 and 3. MS_1 is given by:

$$MS_1 = \frac{1}{3}\sum \frac{S}{N}\ ratio\ for\ the\ first\ level\ speed$$
$$= \frac{1}{3}(63.23 + 73.90 + 76.0) = 70.88$$

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. These values are calculated and shown in the Table 5.

Table -5: Significance of machining parameter for MRR

Machining Parameters	Mean S/N Ratio			Significance of Machining Parameter Max-Min
	Level 1	**Level 2**	**Level 3**	
Speed(S)	70.88	71.42	76.99 *	6.11
Feed(F)	70.36	72.76	76.17 *	5.81
Depth of Cut(D)	68.12	75.54	75.63 *	7.51

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. The best parameters for material removal rate has been found in Table 2 as cutting speed 1000 RPM in level 3, feed 0.20 mm/rev in level 3 and depth of cut 1.5 mm in level 3. From this analysis, we come across that the factor depth of cut has the most significant factor and its contribution to material removal rate is more. The next significant factor is speed and then significant factor is feed. The effect of parameters i.e. cutting speed, feed rate and depth of cut and some of their interactions were evaluated using ANOVA analysis. The purpose of the ANOVA was to identify the important parameters in prediction of Material removal rate.

Table -6: Analysis of variance and F-test for MRR

Factor	SS_D	DF	MS	F	%C
Speed	68.58	2	34.29	54.53	29.52
Feed	51.07	2	25.53	40.61	21.98
Depth of Cut	111.39	2	55.70	88.57	47.95
Error	1.26	2	0.629		
Total	232.31	8			

6.3 F- Test

F-test is used to determine which process parameters have a significant effect on the quality characteristic. The variance ratio denoted by F is given by

$$F = \frac{MS_{model}}{MS_{error}}$$

A large value of F means the effect of that factor is very large as compared to the error variance.

F for speed factor = Mean square of speed factor / Mean square of error factor = 54.53

Similarly, F for feed factor = 40.61 and F for depth of cut factor = 88.57

The degree of freedom for speed, feed and depth of cut represented by $n_1 = 2$ and that of error factor is $n_2 = 2$.

$$F^{C.V.}_{\alpha=0.05, n_1=2, n_2=2} = 19.00$$

Since our F-ratio is greater than this critical value we can reject H_0 and conclude that at least one of the cutting parameters has a different mean at a 5% level of significance.

6.4 Determining which means is/are different

There are many techniques for testing the differences between means, paper has considered Least Significant Difference (LSD) Test.

$$LSD = \sqrt{\frac{2 * MSE * F_{0.05,2,2}}{r}} = \sqrt{\frac{2 * 0.629 * 19.0}{3}} = 2.82$$

Where, MSE is the mean square error and r is the number of rows in each experiment.

From Table 2, $\overline{x_s}$ =800, $\overline{x_f}$ =0.15 and $\overline{x_d}$ =1.0

$$|\overline{x_s} - \overline{x_f}| = 799.85 > 2.82$$

$$\Rightarrow mean\ head\ pressure\ is\ statically\ different\ between\ speed\ and\ feed$$

$$|\overline{x_s} - \overline{x_d}| = 799.0 > 2.82$$

$$\Rightarrow mean\ head\ pressure\ is\ statically\ different\ between\ speed\ and\ depth\ of\ cut$$

$$|\overline{x_d} - \overline{x_f}| = 0.85 < 2.82$$

$$\Rightarrow mean\ head\ pressure\ is\ statically\ different\ between\ depth\ of\ cut\ and\ feed$$

7. CONCLUSIONS

The research has demonstrated an application of the Taguchi method for investing the effects of cutting parameters on material removal rate in turning aluminum metal. With analysis of results in this work using S/N ratio approach and ANOVA provides a systematic and efficient methodology for the optimization of cutting parameters. The material removal rate is mainly affected by cutting speed, depth of cut and feed rate, by increasing any one the material removal rate is increased. The parameters considered in this experiment are optimized to attain maximum material removal rate. The best parameters for material removal rate has been found in Table 2 as cutting speed 1000 RPM in level 3, feed 0.20 mm/rev in level 3 and depth of cut 1.5 mm in level 3 on the basis of ANOVA analysis

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