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Optimization of Metal Removal Rate for 6061 Aluminum in Turning Operation Using ANOVA, Taguchi & Fuzzy Logic

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Abstract—
Optimization is a method through which better results are attained under certain circumstances. The chief objective of today's contemporary manufacturing industries is to produce low cost and high quality products in short time. The selection of optimal cutting parameters is a very significant concern for every machining process in order to augment the quality of machining products and diminishes the machining costs. This research work signifies on an optimization of metal removal rate in turning operation by applying Taguchi, ANOVA (Analysis of Variance) & fuzzy logic method to deduce the effect of the cutting parameters on metal removal rate. For research 6061 aluminium has been considered as workpiece and spindle speed, feed rate & depth of cut have been taken as cutting parameters, whereas HSS (High Speed Steel) has been used as cutting tool for turning. The fuzzy optimization that reflects in fuzzy modeling heightens this research work more precisely.

Keywords-- Metal Removal Rate (MRR); ANOVA; Design of Experiments; Taguchi Method; Fuzzy logic

I. INTRODUCTION

Turning is one of the most usually used metal removal operations in industry because of its aptitude to remove material faster giving reasonably good surface quality. It is used in a variety of manufacturing industries comprising aerospace and automatic sectors. During turning process we expect highest metal removal rate so as to achieve highest production at reduced time and cost. Metals from the outer periphery of a cylindrical work piece is removed and the volume of metal removed per unit time is known as metal removal rate or MRR. A turning machine or lathe, workpiece, fixture, and cutting tool are required during the turning operation. The workpiece is a piece of re-shaped metal that is secured to the fixture, which itself is attached to the turning machine, and allowed to rotate at high speeds. The cutter is typically a single-point cutting tool that is also secured in the machine. The cutting tool feeds into the revolving work piece and cuts away material in the form of small chips to generate the desire shape.

Tong L. et al. (1997), proposed a procedure in this study to achieve the optimization of multi-response problems in the Taguchi method which includes four phases, i.e. computation of quality loss, determination of the multi-response S/N ratio, determination of optimal factor/level condition and performing the confirmation experiment [1].

The Taguchi method has been widely used in engineering analysis and is a powerful tool to design a high quality system. Moreover, the Taguchi method employs a special design of orthogonal array to investigate the effects of the entire machining parameters through the small number of experiments. By applying the Taguchi technique, the time required for experimental investigations can be significantly reduced, as it is effective in the investigation of the effects of multiple factors on performance as well as to study the influence of individual factors to determine which factor has more influence [2].

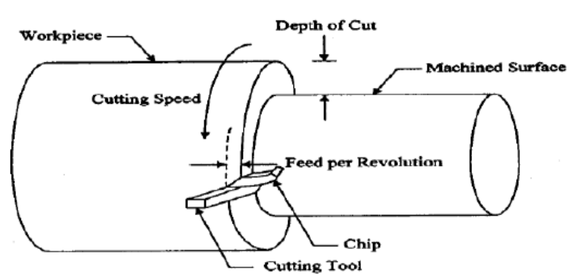

Figure 1. Turning Operation

II. LITERATURE REVIEW

In fact an optimization problem is the problem of judgment the best solution from all possible solutions where finding an alternate or parameter with the most cost effective as well as peak achievable performance under the given constraints. In our research work fuzzy logic has been used to consider the uncertainty and to compare with results derived from ANOVA and Taguchi method.

Rogov Vladimir Aleksandrovich, Ghorbani Siamak(2013) found from their experimental studies " The smallest Ra values occurring in turning of AISI 1045 steel are 1.033 µm and 0.569 µm for standard cutting tool and cutting tool with holes in toolholder, respectively. The smallest natural frequency values occurring in turning of AISI 1045 steel are 2069.1 Hz and 2124 Hz for standard cutting tool and cutting tool with holes in toolholder, correspondently. Using ANOVA, the most significant parameter was determined, which was spindle speed for Ra, while this variable was tool overhang for natural frequency for both cutting tools" [3].

Bhattacharjya S. *et al.* (2011) showed the application of non-linear mathematical programming technique in the case of optimization problem solving. On this work it has shown that uncertainty is inevitable in the characterization of a structure and disregarding the presence of uncertainty may lead to improper design and catastrophic consequences in many cases [4].

Neeraj Saraswat1, Ashok Yadav 2, Anil Kumar3 and Bhanu Prakesh Srivastava4 (2014), found from their experimental studies "Taguchi method has been adopted for the design of experiments and results have been by minimizing S/N ratio. Optimization of the surface roughness was done using Taguchi method and Predictive equation was obtained. A confirmation test was then performed which depicted that the selected parameters and predictive equation were accurate to within the limits of the measurement instrument" [5].

Tsao and Hocheng *et al.* (2008) performed the extrapolation and estimation of thrust force and exterior roughness in drilling of composite material. They used Taguchi and the artificial neural network methods on this optimization problem [6].

M. Adinarayana1, G. Prasanthi2, G. Krishnaiah3 found from their studies, "The feed rate has the variable effect on surface Roughness, cutting speed and depth of cut an approximate decreasing trend. Cutting speed, feed rate and depth of cut for Material Removal Rate have increasing trend. Power Consumption is increase with increase in cutting speed, feed rate and depth of cut. Analysis of Variance (ANOVA) is done and found that it shows The depth of cut has great influence for the Response surface roughness (31.78%), Speed has great Influence for the response Material removal rate (55.56%), and Depth of cut has great influence for the Response Power consumption (66.75%)" [7].

Kurt *et al.* (2009) used the Taguchi method in the optimization of cutting parameters for surface finish and hole diameter accuracy in dry drilling processes [8].

Deepak Mittal, M. P. GARG, RAJESH KHANNA(2011),"This study reveals that during machining of Titanium grade 2 on conventional lathe machine, MRR is affected by all the process parameters viz. spindle speed, depth of cut and feed rate. The MRR is increased by increasing any of the process parameters. The effect of variation in spindle speed and feed rate is more as compared to depth of cut. The tool failure takes place at higher values of depth of cut, feed rate and spindle speed. So in order to avoid the tool failure a compromise in the MRR must be made. This study is carried out for bracketing the optimum range of three input parameters for carrying out further research" [9].

Shivade A. and Shinde V. (2014) used wire electrical discharge machining of D3 tool steel for multi-objective optimization in WEDM. Influence of pulse-on time, pulse-off time, peak current and wire speed were investigated for MRR. By Analysis of variance (ANOVA) they showed that the peak current was the most significant parameters affecting on multi-objective characteristics. By taguchi method the ranks and the delta values showed that current had the greatest effect on MRR and was followed by pulse on time, peak current, pulse off time and wire speed in that order [10].

Tahriri F. *et al.* (2014) studied about the application of fuzzy Delphi and fuzzy inference system in supplier ranking and selection. Here the six aspects and thirteen criteria for supplier selection model were proposed. The six aspects were including trust, quality, cost, delivery, management and organization, financial; in which ''trust'' and ''cost'' were ranked as the top two aspects. The second contribution was the development of a multi-criteria decision making model for evaluating the criteria and selecting the appropriate supplier [11].

III. METHODOLOGY

A. Specification of work material

For performing turning operations 6061 aluminium materials have been used. They were in the form of cylindrical bar of diameter 31mm and cutting length 100 mm. The material composition of 6061 aluminium has given below.

Table 1. Chemical composition of 6061 aluminium.

Mg	Si	Fe	Cu	Zn	Ti	Mn	Cr	Al
0.8 - 1.2	0.4 - 0.8	0.7	0.15 - 0.40	0.25	0.15	0.15	.05-.35	Balanced

B. Process parameters

Table 2. Process parameter & their levels.

Level	Spindle Speed (s) (rpm)	Feed rate(f) (mm/rev)	Depth of cut(d) (mm)
1	112	0.125	0.25
2	175	0.138	0.30
3	280	0.153	0.35

C. Analysis of Variance (ANOVA)

ANOVA is used to determine the influence of any given process parameters from a series of experimental results by design of experiments and it can be used to interpret experimental data. Since there will be large number of process variables which control the process, some mathematical models are required to represent the process. However these models are to be developing using only the significant parameters which influences the process, rather than including all the parameters.

D. Taguchi Method

The Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments (Singh A., *et al.* 2013). The change in quality characteristics of a product response to a factor introduced in the experimental design is the signal of the desired effect. The effect of the external factors of the outcome of the quality characteristic under test is termed as noise. To use the loss function as a figure of merit an appropriate loss function with its constant value must first be established which is not always cost effective and easy. The experiment results are then transformed into a Signal-to-Noise (S/N) ratio. Taguchi recommends the use of S/N ratio to measure the quality characteristics deviating from the desired value. The S/N ratio for each level of process parameters is computed based on the S/N analysis and converted into a single metric. The aim in any experiment is to determine the highest possible S/N ratio for the result irrespective of the type of the quality characteristics. A high value of S/N implies that signal is much higher than the random effect of noise factors. In the Taguchi method of optimization, the S/N ratio is used as the quality characteristic of choice. The different S/N ratio characteristics are given as (Singh A., *et al.* 2013) [12]:

I. Nominal-the-Best(NB)/Target-the-Best (TB),
II. Lower-the-Better (LB),
III. Higher-the-Better (HB)

E. Fuzzy Interference System

Fuzzy logic reflects how people think. It attempts to model our sense of words, our decision making and our common sense. As a result, it is leading to new, more human, intelligent systems.

Fuzzy logic is a set of mathematical principles for knowledge representation based on degrees of membership.

Fuzzy, or multi-valued logic was introduced in the 1930s by Jan Lukasiewicz, a Polish philosopher. While classical logic operates with only two values 1 (true) and 0 (false), Lukasiewicz introduced logic that extended the range of truth values to all real numbers in the interval between 0 and 1. He used a number in this interval to represent the possibility that a given statement was true or false. For example, the possibility that a man 181 cm tall is really tall might be set to a value of 0.86. It is likely that the man is tall. This work led to an inexact reasoning technique often called possibility theory. In 1965 Lotfi Zadeh, published his famous paper "Fuzzy sets". Zadeh extended the work on possibility theory into a formal system of mathematical logic, and introduced a new concept for applying natural language terms. This new logic for representing and manipulating fuzzy terms was called fuzzy logic, and Zadeh became the Master of fuzzy logic [13].

IV. EXPERIMENTATION & MATHEMATICAL MODELING

A. Choice of Orthogonal Array Design

The choice of a suitable orthogonal array (OA) design is critical for the success of an experiment and depends on the total degrees of freedom required to study the main and interaction effects, the goal of the experiment, resources and budget available and time constraints. Orthogonal arrays allow one to compute the main and interaction effects via a minimum number of experimental trials (Ross, 1988). ''Degrees of freedom'' refers to the number of fair and independent comparisons that can be made from a set of observations. In the context of SDOE, the number of degrees of freedom is one less than the number of levels associated with the factor. In other words, the number of degrees of freedom associated with a factor at *p*-levels is (*p*-1). As the number of degrees of freedom associated with a factor at two levels is unity. The number of degrees of freedom associated with an interaction is the product of the number of degrees of freedom associated with each main effect involved in the interaction (Antony, 1998) [14].

B. Mathematical formulation & experimental data

The experiment was conducted for Dry turning operation (without cutting fluid) of using 6061 aluminium as work material and high speed steel as cutting tool on a conventional lathe machine. The tests were carried for a 100 mm cutting length of work material. The process parameters are spindle speed (rpm), feed rete (mm/rev) & depth of cut (mm). The response variable is metal removal rate and the experimental results are recorded in Table 3. Creating orthogonal arrays for the parameter design indicates the number of condition for each experiment. The selection of orthogonal arrays are based on the number of parameters and the level of variation for each parameter.

For the maximum metal removal rate, the solution is "Larger is better" and S/N ratio is determined according to the following equation:

$S/N = 10 \log_{10} \{n^{-1} \sum y^{-2}\}$

Where, S/N = Signal to Noise Ratio,

n = No. of Measurements, y = Measured Value

(a)

(b)

Figure 2. (a) 6061 aluminium after turning operation (b) High speed steel (HSS) cutting tool.

Table 3. Experimental data

Exp no.	Spindle speed (rpm)	Feed rate,f (mm/rev)	Depth of cut,d (mm)	Metal removal rate, MRR (mm^3/s)
1.	112	0.125	0.25	6.11
2.	112	0.125	0.30	7.15
3.	112	0.125	0.35	8.18
4.	112	0.138	0.25	6.25
5.	112	0.138	0.30	7.31
6.	112	0.138	0.35	8.29
7.	112	0.153	0.25	6.44
8.	112	0.153	0.30	7.50
9.	112	0.153	0.35	8.49
10.	175	0.125	0.25	7.72
11.	175	0.125	0.30	8.92
12.	175	0.125	0.35	9.98
13.	175	0.138	0.25	7.97
14.	175	0.138	0.30	9.19
15.	175	0.138	0.35	10.33
16.	175	0.153	0.25	7.91
17.	175	0.153	0.30	9.29
18.	175	0.153	0.35	10.61
19.	280	0.125	0.25	9.73
20.	280	0.125	0.30	11.43
21.	280	0.125	0.35	13.05
22.	280	0.138	0.25	9.63
23.	280	0.138	0.30	11.36
24.	280	0.138	0.35	12.85
25.	280	0.153	0.25	9.51
26.	280	0.153	0.30	11.20
27	280	0.153	0.35	12.81

Table 4. Response table of means for MRR

Level	Spindle speed	Feed rate	Depth of cut
1.	7.30	9.14	7.92
2.	9.10	9.24	9.26
3.	11.29	9.31	10.51

Table 5. ANOVA for the response Metal removal rate

Source	DOF	Sum of square	Mean of square	F ratio	% of contribution
Spindle speed	2	71.87	35.93	51.33	69.38
Feed rate	2	0.13	0.07	0.10	0.13
Depth of cut	2	30.20	15.10	21.57	29.15
Error	2	1.39	0.70		1.34
Total	8	103.59			100

From the above Table 5, it is observed that the spindle speed (69.38%), depth of cut (29.15%) have great influence on metal removal rate. The parameter feed rate (0.13%) has small influence. Since this is a parameter based optimization design, from the above values it is clear that spindle speed (69.38%) is the prime factor to be effectively selected to get the effective metal removal rate.

Design of experiment for metal removal rate L9 orthogonal array is prepared by carrying out a total number of 9 experiments along with 2 verification (X and Y data) experiments. For Y data, 9 set of new experiments is conducted in terms of data representation of Table 6. In L9 array 9 rows represent the 9 experiment to be conducted with 3 columns at 3 levels of the corresponding factor. The matrix form of this array is shown in Table 6.

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Table 6. Calculation of signal to noise ratio for MRR

Exp. No	Parameters level			MRR (mm^3/s)		Signal to noise ratio (S/N ratio)
	Spindle speed	Feed rate	Depth of cut	X	Y	
1.	112	0.125	0.25	6.11	6.13	52.72
2.	112	0.138	0.30	7.31	7.34	50.76
3.	112	0.153	0.35	8.49	8.51	55.58
4.	175	0.125	0.30	8.92	8.96	50.00
5.	175	0.138	0.35	10.33	10.38	49.33
6.	175	0.153	0.25	7.91	7.95	48.95
7.	280	0.125	0.35	13.05	13.09	53.29
8.	280	0.138	0.25	9.63	9.67	50.66
9.	280	0.153	0.30	11.20	11.24	51.97

Table 7. Response table for signal to noise ratio for MRR

Level	Spindle speed	Feed rate	Depth of cut
1.	53.02	52.00	50.78
2.	49.43	50.25	50.91
3.	51.97	52.16	52.73
Delta(max-min)	3.59	1.91	1.95
Rank	1	3	2

From Table 7 it is clear that the spindle speed is the most significant parameter for maximizing metal removal rate as its rank is first.

C. Fuzzy logic model for 6061 aluminium in turning operation :(Metal Removal Rate as response)

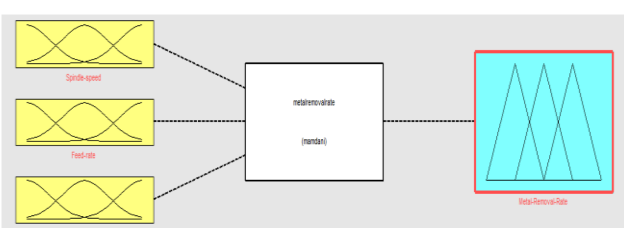
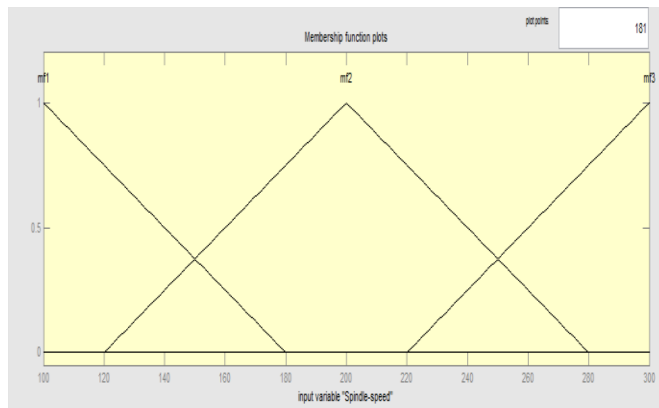


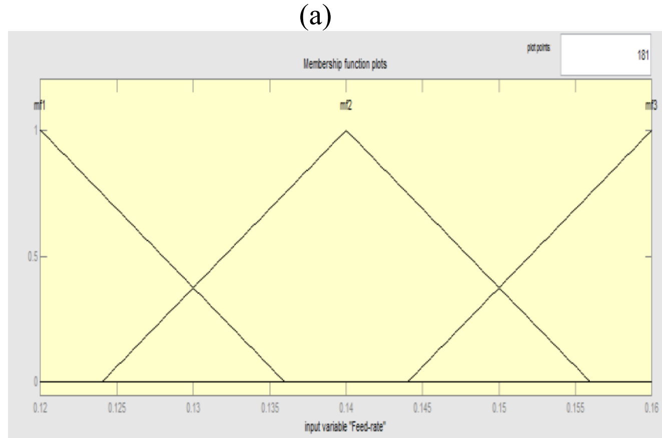
Figure 3. Fuzzy logic model for 6061 aluminium in turning operation :(response MRR)

Membership function for the input and output parameters (MRR as response):

This step is to define linguistic values assigned to the variables by the fuzzy subsets and their associated membership functions which may be zero or one called the grades of membership. Zero membership value indicated that it is not a member of the fuzzy set & one represents a complete member. A membership function can have any shape but preferably should be symmetric which includes trapezoidal, triangular & bell shaped. Three membership function were generated for each input variable (Spindle speed, Feed rate, Depth of cut) as shown in figure 4(a, b, c)



(a)



(b)

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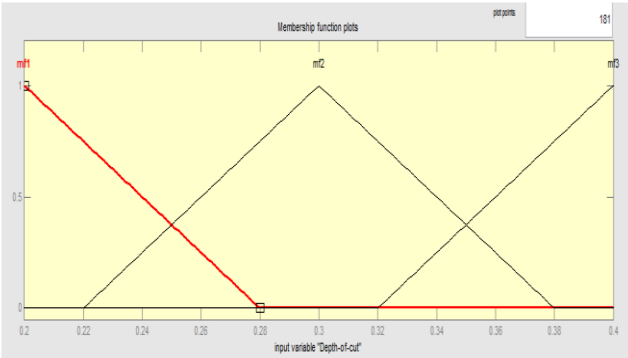

(c)

Figure 4. Membership function plots for input parameters (a) Spindle speed (b) Feed rate (c) Depth of cut

Membership functions for MRR as output variable of the metal is shown in figure 5

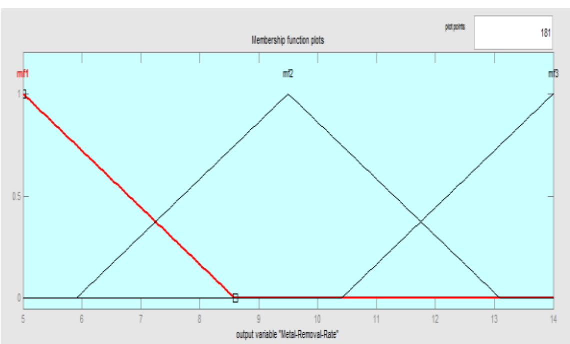

Figure 5. Membership functions for output parameter (MRR)

FIS rules employed in model (MRR as response):
For obtaining optimized solution, the rules at the base have been defined correctly & these rules have written based upon the experimental results. While preparing the rules, fuzzy method has been used. Some selected rules are reported in fig.6, fuzzy using MATLAB R2014a using Mamdani type of fuzzy interference system in fuzzy logic toolbox.

1. If (Spindle-speed is mf1) and (Feed-rate is mf1) and (Depth-of-cut is mf1) then (Metal-Removal-Rate is mf1) (1)
2. If (Spindle-speed is mf1) and (Feed-rate is mf1) and (Depth-of-cut is mf2) then (Metal-Removal-Rate is mf1) (1)
3. If (Spindle-speed is mf1) and (Feed-rate is mf1) and (Depth-of-cut is mf3) then (Metal-Removal-Rate is mf1) (1)
4. If (Spindle-speed is mf1) and (Feed-rate is mf2) and (Depth-of-cut is mf1) then (Metal-Removal-Rate is mf1) (1)
5. If (Spindle-speed is mf1) and (Feed-rate is mf2) and (Depth-of-cut is mf2) then (Metal-Removal-Rate is mf1) (1)
6. If (Spindle-speed is mf1) and (Feed-rate is mf2) and (Depth-of-cut is mf3) then (Metal-Removal-Rate is mf1) (1)
7. If (Spindle-speed is mf1) and (Feed-rate is mf3) and (Depth-of-cut is mf1) then (Metal-Removal-Rate is mf1) (1)
8. If (Spindle-speed is mf1) and (Feed-rate is mf3) and (Depth-of-cut is mf2) then (Metal-Removal-Rate is mf1) (1)
9. If (Spindle-speed is mf1) and (Feed-rate is mf3) and (Depth-of-cut is mf3) then (Metal-Removal-Rate is mf1) (1)
10. If (Spindle-speed is mf2) and (Feed-rate is mf1) and (Depth-of-cut is mf1) then (Metal-Removal-Rate is mf1) (1)
11. If (Spindle-speed is mf2) and (Feed-rate is mf1) and (Depth-of-cut is mf2) then (Metal-Removal-Rate is mf2) (1)
12. If (Spindle-speed is mf2) and (Feed-rate is mf1) and (Depth-of-cut is mf3) then (Metal-Removal-Rate is mf2) (1)
13. If (Spindle-speed is mf2) and (Feed-rate is mf2) and (Depth-of-cut is mf1) then (Metal-Removal-Rate is mf1) (1)
14. If (Spindle-speed is mf2) and (Feed-rate is mf2) and (Depth-of-cut is mf2) then (Metal-Removal-Rate is mf2) (1)
15. If (Spindle-speed is mf2) and (Feed-rate is mf2) and (Depth-of-cut is mf3) then (Metal-Removal-Rate is mf2) (1)
16. If (Spindle-speed is mf2) and (Feed-rate is mf3) and (Depth-of-cut is mf1) then (Metal-Removal-Rate is mf1) (1)
17. If (Spindle-speed is mf2) and (Feed-rate is mf3) and (Depth-of-cut is mf2) then (Metal-Removal-Rate is mf2) (1)
18. If (Spindle-speed is mf2) and (Feed-rate is mf3) and (Depth-of-cut is mf3) then (Metal-Removal-Rate is mf2) (1)
19. If (Spindle-speed is mf3) and (Feed-rate is mf1) and (Depth-of-cut is mf1) then (Metal-Removal-Rate is mf2) (1)
20. If (Spindle-speed is mf3) and (Feed-rate is mf1) and (Depth-of-cut is mf2) then (Metal-Removal-Rate is mf2) (1)
21. If (Spindle-speed is mf3) and (Feed-rate is mf1) and (Depth-of-cut is mf3) then (Metal-Removal-Rate is mf3) (1)
22. If (Spindle-speed is mf3) and (Feed-rate is mf2) and (Depth-of-cut is mf1) then (Metal-Removal-Rate is mf2) (1)
23. If (Spindle-speed is mf3) and (Feed-rate is mf2) and (Depth-of-cut is mf2) then (Metal-Removal-Rate is mf2) (1)
24. If (Spindle-speed is mf3) and (Feed-rate is mf2) and (Depth-of-cut is mf3) then (Metal-Removal-Rate is mf2) (1)
25. If (Spindle-speed is mf3) and (Feed-rate is mf3) and (Depth-of-cut is mf1) then (Metal-Removal-Rate is mf2) (1)
26. If (Spindle-speed is mf3) and (Feed-rate is mf3) and (Depth-of-cut is mf2) then (Metal-Removal-Rate is mf2) (1)
27. If (Spindle-speed is mf3) and (Feed-rate is mf3) and (Depth-of-cut is mf3) then (Metal-Removal-Rate is mf2) (1)

Figure 6. Formulation of rules (Response MRR)

The set of rules along with membership function is shown in rule viewer of fuzzy model (Figure 6). Figure 6 reveals that after the formulation of rules, the optimum value of metal removal rate at any setting between the low & high limits of the process parameters can be predicted.

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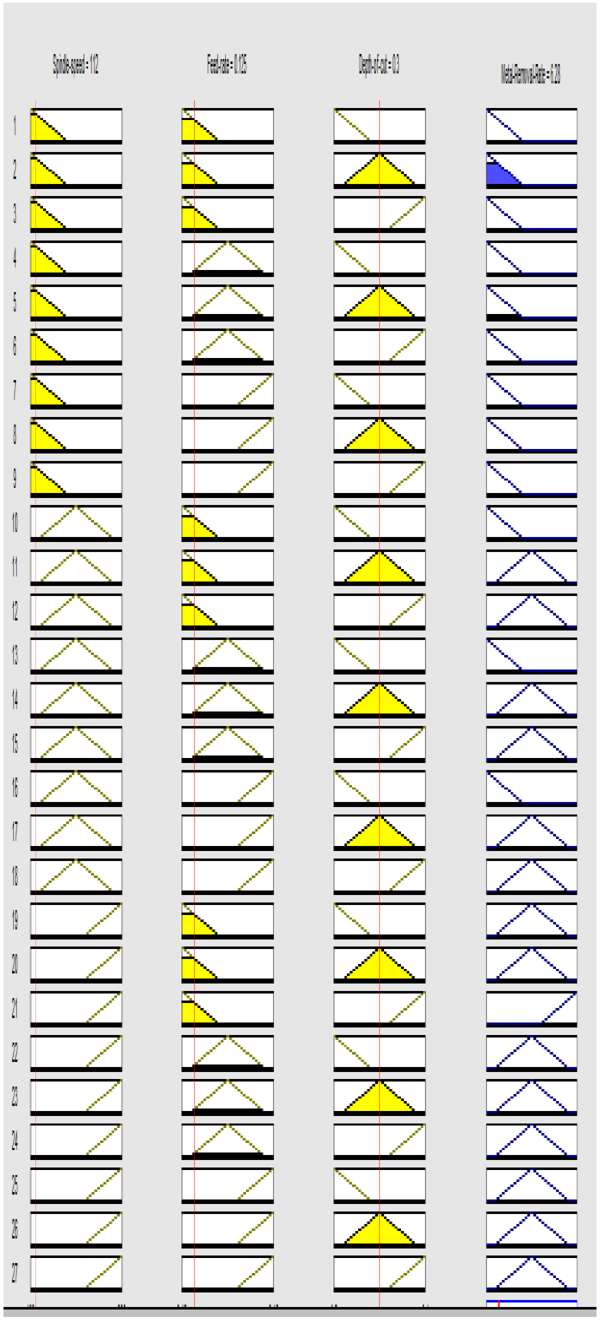
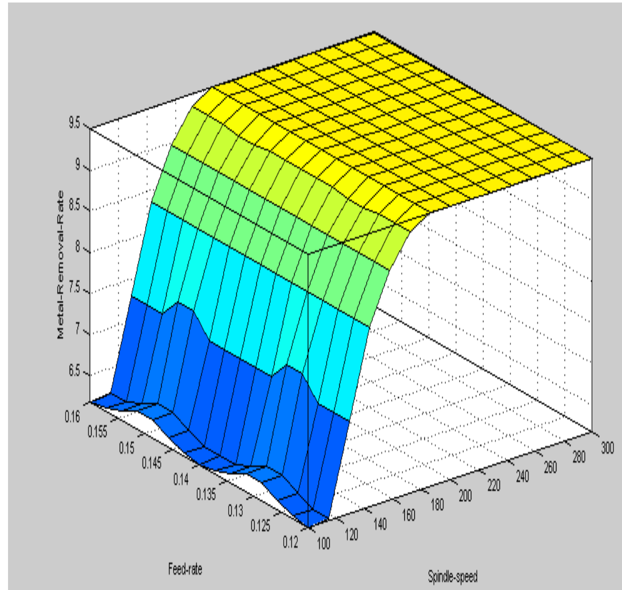
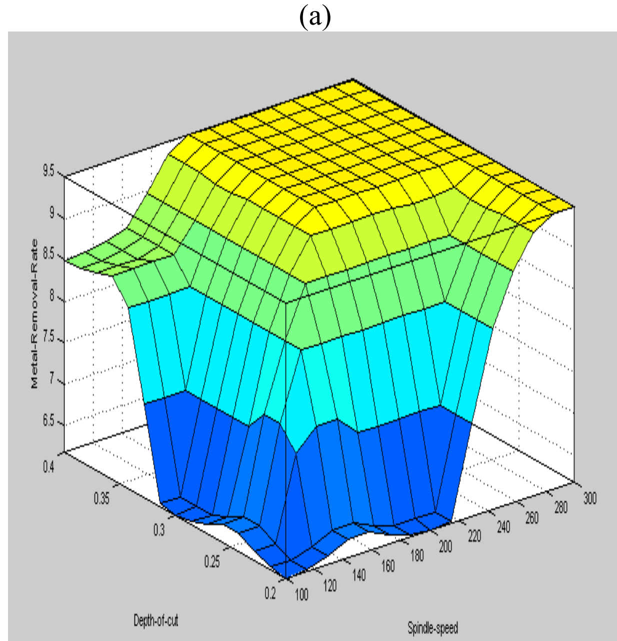


Figure 7. Rule viewer of fuzzy model

Figure 7 shows that at spindle speed 112 rpm, feed rate 0.125 mm/rev, depth of cut 0.30 mm predicts optimum value of MRR as 6.28 mm^3/sec. Similarly, for different sets of data points MRR in turning operation can be predicted from the fuzzy model.



(a)



(b)

Figure 8. Control surfaces of fuzzy model

Control surfaces in figure 8 give the interdependency of input & output parameters.

Table 8. Comparison of fuzzy model and experimental data.

Exp. no.	Experimental value of MRR (mm^3/sec)	Fuzzy value	% variation
1.	6.11	6.46	5.73
2.	7.15	6.28	12.17
3.	8.18	6.46	21.03
4.	6.25	6.46	3.36
5.	7.31	6.20	15.18
6.	8.29	6.46	22.07
7.	6.44	6.46	0.31
8.	7.50	6.34	15.47
9.	8.49	6.46	23.91
10.	7.72	8.69	12.56
11.	8.92	9.43	5.72
12.	9.98	9.39	5.91
13.	7.97	8.69	9.03
14.	9.19	9.43	2.61
15.	10.33	9.39	9.10
16.	7.91	8.69	9.86
17.	9.29	9.42	1.40
18.	10.61	9.39	11.50
19.	9.73	9.50	2.36
20.	11.43	9.50	16.89
21.	13.05	10.30	21.07
22.	9.63	9.49	1.45
23.	11.36	9.51	16.28
24.	12.85	9.50	26.07
25.	9.51	9.52	0.11
26.	11.20	9.50	15.18
27	12.81	9.50	15.83

V. RESULTS AND DISCUSSION

A. Equation for Optimization of Metal Removal Rate

From the linear regression analysis (running a program in IBM SPSS Statistics) the following equation has derived:

MRR= -3.783+0.023*(Spindle speed) +5.872*(Feed rate) + 25.911*(Depth of cut)

B. Graphical Representation

From the above experimental results, three methods of data analysis have been used which draw similar assumptions. The spindle speed has found to be the most significant effect to produce high value of metal removal rate (MRR) form the graph of the IBM SPSS Statistics. S/N ratio is used for choosing the best levels of combination for metal removal rate (MRR) value which mentions the use of high value of spindle speed & depth of cut in order to obtain good metal removal rate. Therefore, it is preferable to set the spindle speed to a high value. From the table 3 it is clear that the optimal cutting parameters are level 3 of spindle speed & depth of cut and level 1 of feed rate in table 2 to obtain good amount of metal removal rate (MRR) and which is also indicated in table 9. From the result, the interaction of spindle speed and depth of cut is more important than the effect of the individual factors. In other words, in order to get the exceptional result it requires experience to combine these two factors to achieve a suitable combination of spindle speed and depth of cut.

Table 9. Optimal sequence for maximum MRR

Spindle speed	Feed rate	Depth of cut	Metal removal rate (MRR)
280	0.125	0.35	13.05

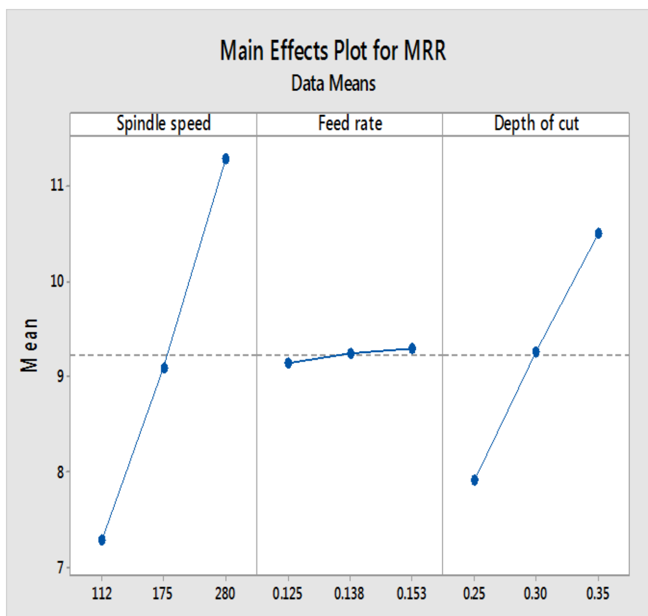


Figure 9. Main effects plot for Metal removal rate.

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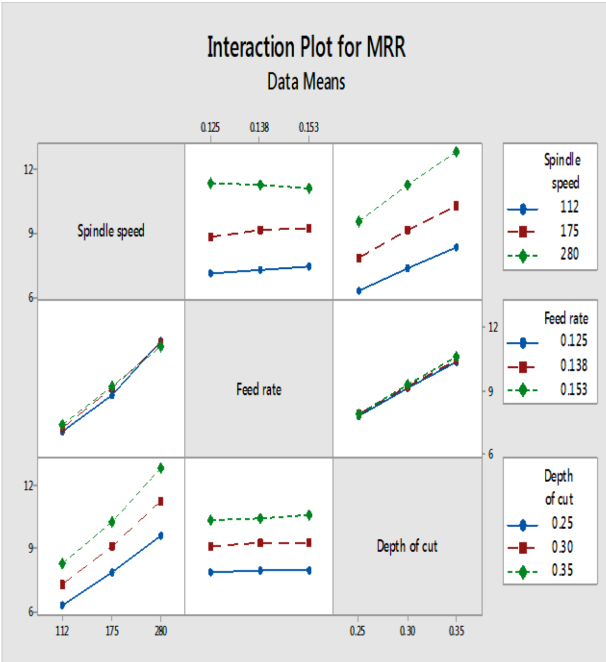


Figure 10. Interaction plot for Metal removal rate.

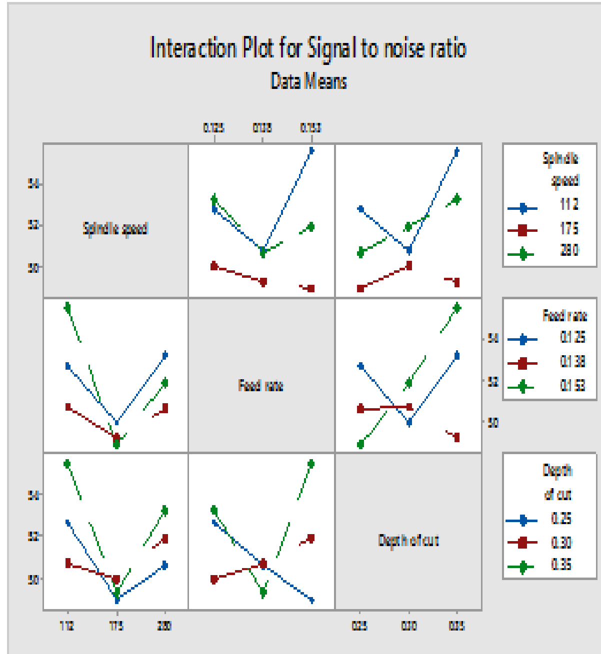


Figure 12. Interaction plot for S/N ratio.

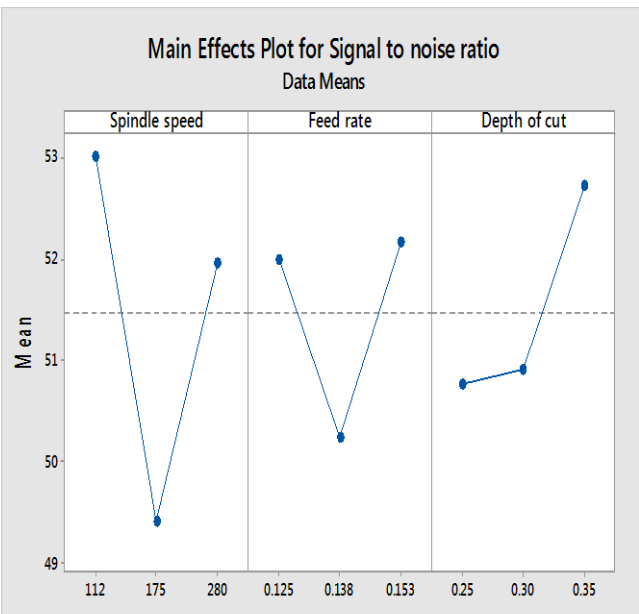
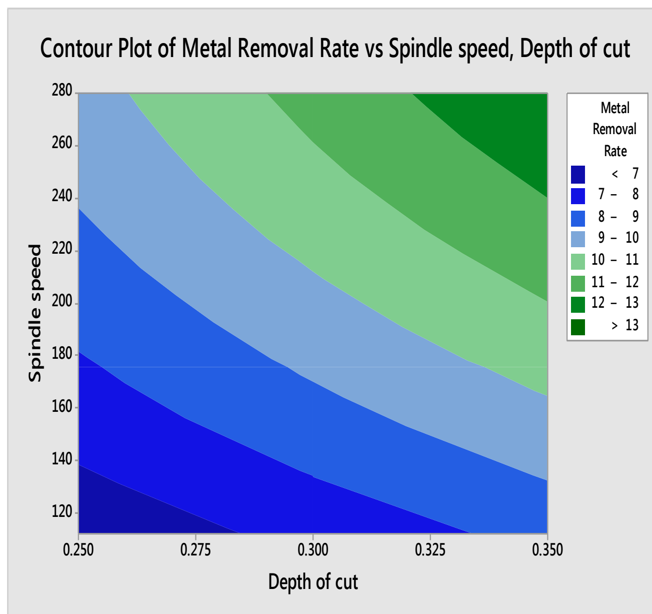


Figure 11. Main effects plot for S/N ratio.



(a)

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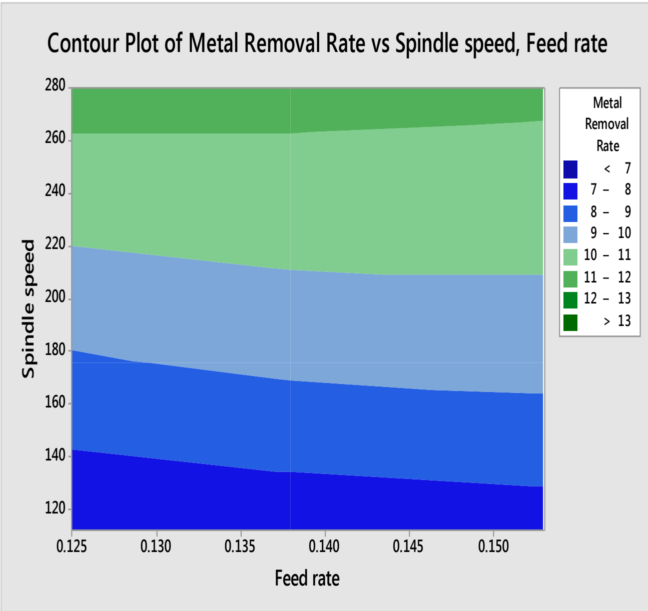

(b)

Figure 13. Contour plot of (a) MRR Vs Spindle speed, Depth of cut (b) MRR Vs Spindle speed, feed rate (for aluminium)

VI. CONCLUSION

This paper deals with the application of the parameter design (Taguchi method) in the optimization of metal removal rate of 6061 aluminium in turning operation. ANOVA is required to know the influence of each factors and their quantitative percentage during operation. After analyzing the results using ANOVA, Taguchi & Fuzzy Logic method it is diaphanous that metal removal rate increases by the augmentation of spindle speed, feed rate & depth of cut. The study discloses that metal removal rate is unswervingly influenced by all the three parameters. The effect of spindle speed & depth of cut is more as compared to feed rate. By ANOVA method percentage contribution of the three parameters & by Taguchi method most significant parameter has found. Spindle speed is the most significant parameter which is found for both ANOVA and Taguchi method. The percentage contribution of the spindle speed is 69.38% in ANOVA analysis and the spindle speed is the first rank in Taguchi method. It is found that the parameter design of the Taguchi method offers a simple, logical, and effective approach for optimizing the process parameters and it is one of the most effective techniques in the field of optimization problem solution. Table-8 gives the comparison of the predicted responses using fuzzy model & conducted experimental data. There appears to be a good settlement between fuzzy model & experimental values in all cases. In the present study there are 27 observations & the average percentage error of various responses from fuzzy experimental model has found to be 11.19%. Accordingly the system has given an overall 88.81% accuracy from fuzzy model. Since cutting fluid & tool wear investigation is not considered in this research work so there are some deviations between experimental & fuzzy values.

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