International Journal of Mechanical Engineering and Robotics Research

ISSN 2278 – 0149 www.ijmerr.com
Vol. 3, No. 3, July, 2014


*Research Paper*

# OPTIMIZATION OF PROCESS PARAMETERS FOR OPTIMAL MRR DURING TURNING STEEL BAR USING TAGUCHI METHOD AND ANOVA

**Sujit Kumar Jha[1]***

*Corresponding Author: **Sujit Kumar Jha** ✉ skj828@gmail.com

In this paper Taguchi method has been applied for optimizing process parameters namely, cutting speed, feed rates and depth of cut during turning of mild steel bar with TIN-coated carbide tools. The analysis of variance (ANOVA) has been applied to identify the significant process parameters influencing material removal rate (MRR). An orthogonal array has been constructed to find the experimental results of machining and further signal-to-noise (S/N) ratio has been computed to construct the analysis of variance (ANOVA) table to study the performance characteristics in dry turning operations. The results of ANOVA analysis have shown that feed has most significant factor on material removal rate (MRR) compare to depth of cut and speed for steel. The confirmation experiments have conducted to validate the optimal parameters and improvement of MRR from initial conditions is 347.2%.

***Keywords:*** Taguchi method, Turning, Cutting parameters, ANOVA, MRR

## INTRODUCTION

The optimization techniques have been applied to find out the right level or value of the parameters that have to be maintained for obtaining quality products/services. The optimal selection of the process parameters can be introduced during early stage of the product and process development to achieve the quality product with cost effectiveness. 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 is the main concern of metal-based industries. Productivity can be interpreted in terms of MRR and in machining conditions quality can be interpreted in terms of surface roughness. An increase in productivity results in decrease in machining time which may result in quality loss and vice-versa. The high speed machining (HSM) and modern machining technologies are being used to

[1] Engineering Department, Ibra College of Technology, Ibra, Sultanate of Oman.

machine the parts that need significant amount of material removal. Turning is 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 described by (Rao, 2008).

The present study applied Taguchi method to find out which process parameters having more influence on maximum material removal rate while turning mild steel bar work piece on EMCO MAT 20D conventional lathe. The paper has considered three cutting parameters namely cutting speed, feed rate and depth of cut to optimize the economics of machining operations based on productivity, which further depends on MRR. Higher MRR is desired by the industry for fast production in short time, which can be improved by increasing the process parameters namely cutting speed, feed and depth of cut. However, high cutting speed need more power and at the same time temperature between tool and work-piece increase, which give detrimental in both the product and tool. So, selection of suitable process parameters plays a vital role in efficiency and overall economy of the product to achieve the higher MRR. This paper depicts the turning of mild steel with parameters of turning at three levels and three factors each as considered by some researchers like (Thamizhmanii *et al*., 2007; Kadirgama *et al*., 1996). (Haddad and Fadaei, 2008) have investigated the effects of machining parameters on material removal rate in cylindrical wire discharge turning process using ANOVA and found that high MRR can be obtained by fixing power and voltage parameters as high as possible. Regardless of early works on setting up optimum cutting speeds, feeds on conventional laths or Computerized Numerical Controlled (CNC) machining, the recent research (Kadirgama *et al*., 1996; Sanjit *et al*., 2010; Basim and Basir, 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. There are many mathematical models (Yang and Tarng, 1998; Taguchi *et al*., 2005; Taguchi *et al*., 1998) have been developed based by proper selection of cutting parameters and establish the relationship between the cutting parameters and cutting performance. The paper has applied Taguchi method as another approach to find out the desired cutting parameters more competently based on the detailed description by some researchers (Abuelnaga and El-Dardiry, 1984; Chryssolouris and Guillot, 1990). The optimal cutting parameters have determined by implementing Taguchi method and ANOVA analysis on S45C steel by turning operation presented by (Yang and Tarng, 1998). The optimization of cutting parameters for machining hardened steel has been observed and found that the machining cost and time can be reduced while improving the quality of the product (Gopalsamy *et al*., 2009).

Taguchi method is statistical method developed by Professor Genichi Taguchi for the manufacture of robust products and depicts the quality of a manufactured product as total loss generated by that product from the time it has shipped to society. The robust products can be manufactured by design of the experiment. According to Taguchi, the process and product design can be improved by identifying and setting the easily controllable factors. By setting those factors at their optimal levels, the product can be made robust to changes in operating and environmental conditions. Presently, Taguchi method is applied in many sectors like engineering, biotechnology, marketing and advertising. According to Taguchi, there are two major tools namely, Signal-to-noise (S/N) ratio and orthogonal array has been applied in robust design. Signal to noise ratio 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 for optimal settings of control parameters (Kaladhari and Subbaiah, 2011; Park, 1989). Taguchi method has been implemented for optimizing machining parameters more competently in turning processes by (Aman and Hari, 2005; Sujit *et al*., 2012). 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 (Abhang and Hameedullah, 2011; Khorasani *et al*., 2011; Metin, 2011). (Ezugwu and Okeke, 2010) have investigated the machining of nickel based C-263 alloy at high speed using titanium nitride coated carbide inserts and found that feed rate is more significant than depth of cut in terms of tool life and its performance during machining operation. An experimental analysis has been done to find out the variation of machining parameters on MRR, gap width and surface roughness and graphical results has been presented and analyzed by Liao *et al*. (1997). (Lok and Lee, 1997) have evaluated the machining performance in terms of MRR and surface roughness on ceramics using wire electrical discharge machining. (Krishankant *et al*., 2012) have investigated the effects of machining parameters on EN24 steel by applying Taguchi method to optimize the material removal rate. (Ashok *et al*., 2012) applied Taguchi method for optimization of process parameters in turning AISI 1040 steel and found the impacts of cutting parameters namely cutting speed, feed and depth of cut for surface roughness and material removal rate. They found the cutting speed as the most significant cutting parameter for surface roughness and MRR followed by feed. (Kamal *et al*., 2012) did experimental analysis of turning medium Brass alloy on CNC machine and investigated the effects of cutting parameters on material removal rate and finally based on ANOVA analysis found that that feed rate has most significant effects on MRR.

Several literature reviews have been conducted in order to meet the objectives of this research, to provide background information for paper. This paper has two objectives to investigate the process parameters, 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 Taguchi Method, Section 3 demonstrated Study of material and experimental setup for this research followed by Data analysis results and discussions in Section 4. Finally, Section 5 presents conclusions.

## TAGUCHI METHOD

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 is analyzed to study 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.

The parametric design has been carried out by implementing the Taguchi method to determine an ideal feed rate and desired force combination, the experimental results showed that surface roughness decreases with a slower feed rate and larger grinding force, respectively presented by Liu *et al*., (2005). The detailed description of finding optimal cutting parameters during machining processes has been presented by Taguchi *et al*., (1989). Taguchi has focused in the area of quality loss functions (QLFs), orthogonal arrays (OAs), robust designs, and Signal-to-Noise (S/N) ratios. Generally, on the shop floor technicians applied this method to improve the quality of products and processes. The objective function used in the S/N ratio is maximized, by moving design targets toward the middle of the design space for reducing the effects of the external variation (Taguchi *et al*., 2005).

Antony and Kaye (1999) have implemented Taguchi method by considering 14 design parameters to develop new product by optimizing the manufacturing processes and improved customer satisfaction. (Zhang *et al*., 2007) have applied Taguchi method, which allows controlling the deviation caused by the uncontrollable factors was not included at the conventional design of experiment. 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 (Abuelnaga and El-Dardiry, 1984). (Antony *et al*., 2006) have described S/N ratio used in Taguchi method as a response of the experiment, which is a measure of variation caused by uncontrolled noise factors present in the system. Noise is the result of the quality characteristics influenced by external factors during the test. S/N ratio for the undesired random noise value can be described as the signal ratio. According to Taguchi, S/N ratio has been used to measure the quality characteristics deviating from the preferred value. For each level of process parameters S/N ratio has been computed and identified the highest S/N ratio for the result. The higher S/N ratio value stands for 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) - nearer to the target value is better.
- Lower-the-Better (LB) - it forecast values by considering defects like surface roughness, pin holes or unwanted by-product.
- Higher-the-Better (HB) - larger the better characteristics consists of the desired output as bond strength, material removal rate, employee participation and customer acceptance rate.

For implementation of Taguchi method, an orthogonal array has been designed to calculate the influence of main parameters placed at different rows on the result and interaction effects by doing less number experimental trials (Ross, 1988). The S/N ratio measured the performance characteristics of the levels of control factors against these factors. The category higher-the-better is used to calculate S/N ratio for material removal rate mention in equation (1):

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

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 as well as to examine 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 Kaladhari and Subbaiah (2011). 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.

### Steps Involved in Taguchi Method

For larger-the-better characteristics, Taguchi method have been used for a parameter design includes the following steps (Nian *et al*., 1999):

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.

## EQUIPMENT AND MATERIALS

This paper has considered work piece material as mild steel bar of total length 100 mm and straight turning has been done on 50 mm length of the work piece diameter 24 mm. Young's Modulus of mild steel is 215 GPa, Poisson's ratio is 0.29 and melting point is 1410°C. For proper selection of cutting parameters, a mathematical model for TIN-coated carbide tools has been developed based on statistical techniques to establish the relationship between the cutting performance and the cutting parameters presented by Chua *et al*., (2006). It has been also studied that the effect of the length and diameter of work piece during machining operations, while keeping the cutting speed constant demonstrated by (Mustafa and Ali, 2011). The material removal rate (MRR) plays an important characteristic in turning operation and according to (Gaitonde *et al*., 2003; Paulo Davim, 2003) high MRR is always desirable for increasing the productivity. The details of experiments, experimental variables and constants have been shown in the Table 1.

**Table 1: Experimental Details**

<table>
<tr><th>Details of the Experiment</th><th>Experimental at Variables</th><th>Experimental Constants</th></tr>
<tr><td>Machine used: EMCO MAT - 20D (Conventional Lathe)</td><td rowspan="5">Speed<br>Feed<br>Depth of Cut</td><td rowspan="5">Work Piece: Mild Steel<br>Cutting condition<br>CNC machine<br>Cutting Tool material</td></tr>
<tr><td>Work-piece material: Mild Steel<br>Density of material: 7850 kg/m3<br>Diameter of Work Piece: 24 mm<br>Hardness of Material: 29.8 HRC</td></tr>
<tr><td>Tool material: M42 Series High Speed Steel<br>Shape of Cutting Tool- Triangle</td></tr>
<tr><td>Process parameters: Speed, Feed and Depth of cut</td></tr>
<tr><td>Cutting Condition: Dry Machining</td></tr>
</table>

The experiments were conducted on EMCO MAT 20D conventional lathe, which is highly versatile and up to date with the latest technology. EMCO MAT 20D lathe has a high tech 3 axes digital display, 999 tool positions with stepless 4 staged gearbox - power 5.3 kW, 40 - 3000 rpm 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: Swing diameter over bed: 400 mm, Swing diameter over cross slide: 250 mm, Distance between Centres: 1000 mm, Spindle speed: 40 - 3000 rpm,

**Figure 1: EMCO MAT 20D Conventional Lathe**

Spindle bore: 50 mm, Chuck diameter max: 200 mm.

### Selection of Cutting Parameters and Their Levels

In this paper, there are three cutting parameters: cutting speed, feed rate and depth of cut are considered for three levels as the control factors. Three variables are studied for three levels and hence nine experiments were designed and conducted based on Taguchi's L9 orthogonal array. The initial cutting parameters have been taken as cutting speed of 45 m/min, a feed rate of 0.11 mm/rev, and a depth of cut 0.5 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 | Levels of factors | | |
|---|---|---|---|---|---|
| | | | Level 1 | Level 2 | Level 3 |
| Cutting speed | A | m/min | 30 | 45 | 60 |
| Feed rate | B | mm/rev | 0.05 | 0.11 | 0.22 |
| Depth of cut | C | mm | 0.5 | 1.0 | 1.5 |

## DATA ANALYSIS, RESULTS AND DISCUSSIONS

Experimental results and their corresponding S/N ratios have been computed for each level of process parameters and shown in Table 4. ANOVA has been carried out to observe the significance of factors on responses. Lastly, confirmation test has conducted to verify the optimal results. An orthogonal array has been used to find out the optimal cutting parameters in reduce number of cutting experiments. The results of an orthogonal array have been further studied by using S/N ratio and ANOVA analyses. The optimal cutting parameters have been determined from the results of S/N ratio and ANOVA analyses.

### Orthogonal Array Experiment

A suitable orthogonal array has been designed for experiments based on the degrees of freedom. The experimental plan has been designed based on Taguchi $L_9$ orthogonal array as given in Table 3.

**Table 3: Experimental Layout Using an L9 Orthogonal Array**

| Experimental No. | Machining parameter level | | |
|---|---|---|---|
| | Cutting Speed | Feed Rate | Depth of cut |
| 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 |

## Analysis of the Signal-to-Noise (S/N) Ratio

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

Material removal rate (MRR) can be calculated using the difference of weight of work piece before and after the machining operation.

**Table 4: Experimental Results for MRR and S/N Ratio**

| Exp. No. | Control Parameter (Level) | | | Result / Observed Value | | | |
|---|---|---|---|---|---|---|---|
| | Cutting Speed (m/min) | Feed (mm/rev) | Depth of Cut (mm) | Cycle Time to Remove Material (sec) | MRR (gm/min) | MRR (mm3 min) | S/N Ratio (dB) |
| 1 | 30 | 0.05 | 0.5 | 131 | 3.346 | 426.27 | 52.59 |
| 2 | 30 | 0.11 | 1.0 | 66 | 12.884 | 1641.34 | 64.30 |
| 3 | 30 | 0.22 | 1.5 | 33 | 36.552 | 4656.31 | 73.36 |
| 4 | 45 | 0.05 | 1.0 | 87 | 8.711 | 1109.68 | 60.90 |
| 5 | 45 | 0.11 | 1.5 | 44 | 24.433 | 3112.06 | 69.86 |
| 6 | 45 | 0.22 | 0.5 | 22 | 15.335 | 1953.50 | 65.82 |
| 7 | 60 | 0.05 | 1.5 | 66 | 14.495 | 1846.55 | 65.33 |
| 8 | 60 | 0.11 | 0.5 | 33 | 9.213 | 1173.74 | 61.39 |
| 9 | 60 | 0.22 | 1.0 | 16 | 35.374 | 4506.25 | 73.07 |
| **The total mean S/N ratio = 65.18 dB** | | | | | | | |

$$MRR = \frac{W_i - W_f}{\rho . t} \quad ...(2)$$

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, $\rho$ 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.

The response table, which contains the mean of the S/N ratios for each level and for each factor is shown in the Table 5. For example, the sum of S/N ratio for cutting speed at levels 1, 2, and 3 has been 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:

$$MS_1 = \frac{1}{3}\sum S/N \text{ ratio for the first level speed} = \frac{1}{3}(52.59+64.30+73.36)=63.42$$

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 6, called the mean S/N response table for MRR.

**Table 5: S/N Response Table to Identify Significance of Machining Parameter for MRR**

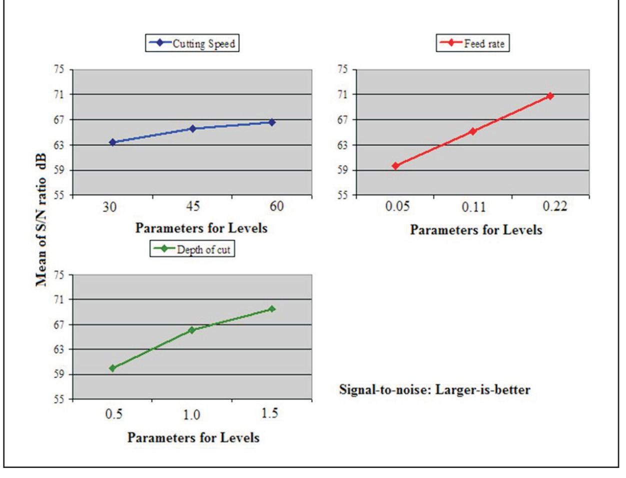
| Machining Parameters | Symbol | Mean S/N Ratio (dB) | | | Significance of Machining Parameter Max-Min |
|---|---|---|---|---|---|
| | | Level 1 | Level 2 | Level 3 | |
| Cutting speed (m/min) | A | 63.42 | 65.52 | 66.60 * | 3.18 |
| Feed rate (mm/rev) | B | 59.60 | 65.18 | 70.75 * | 11.15 |
| Depth of cut (mm) | C | 59.93 | 66.09 | 69.52 * | 9.59 |

Figure 2 shows the main effect on material removal rate which is primarily due to feed and depth of cut. The cutting speed is found to be least significant from the main effect plot. From Table 5 and Figure 2, 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 lathe for mild steel material. Therefore, based on Table 5 and Figure 2, the optimal process parameters for MRR are as follows: Cutting speed at level 3 is 60 m/min, feed at level 3 is 0.22 and depth of cut at level 3 is 1.5 mm i.e. A3-B3-C3. The confirmation test has been conducted with above optimal combination of process parameters for MRR and improvement in S/N ratio as 10.80 dB has been noticed in Table 7. Based on the results of confirmation test, the improvement of MRR from initial cutting parameters is around 347.2%.

## Analysis of Variance (ANOVA) For MRR

The purpose of the ANOVA is to investigate which process parameter has more impacts on performance characteristic. F-test can be

**Figure 2: Main Effect Plot for S/N Ratio (MRR)**




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 | SSD | DF | MS | F | %C |
|---|---|---|---|---|---|
| Speed | 15.69 | 2 | 7.845 | 17.43 | 4.56 |
| Feed | 186.48 | 2 | 93.24 | 207.20 | 54.23 |
| Depth of Cut | 141.67 | 2 | 70.835 | 157.41 | 41.20 |
| Error | 0.90 | 2 | 0.45 | | |
| Total | 344.75 | 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 60 m/min in level 3, feed 0.22 mm/rev in level 3 and depth of cut 1.5 mm in level 3. From above analysis, it is revealed 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.

## 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 (Yang and Tarng, 1998):

$$\eta_{predicted} = \eta_m + \sum_{i=1}^{o} (\eta_i - \eta_m) \qquad ...(3)$$

where $\eta_m$ is the total mean of the S/N ratio, $\eta_i$ 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. (2). The measuring data and the actual S/N ratio of confirmation experiments are listed in Table 7. Table 7 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 10.8 dB, which means that MRR is increased by about 3.47 times. Therefore, prior design and analysis for optimizing the cutting parameters required for optimum MRR.

**Table 7: Results of Conformation Test for MRR**

| | Initial Cutting Parameter | Optimal Cutting Parameter | |
|---|---|---|---|
| | | Predicted | Experiment |
| Level | A2B2C1 | A3B3C3 | A3B3C3 |
| MRR ($mm^3$/min) | 2326 | 6760 | 8076 |
| S/N ratio (dB) | 67.34 | 76.6 | 78.14 |
| Improvement of S/N ratio = 10.80 dB | | | |

# CONCLUSION

The experimental results based on S/N ratio and ANOVA analysis provides a systematic and efficient methodology for the optimization of cutting parameters for MRR. 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 result based on F-test shows that feed rate has more impact on performance characteristic than cutting and depth of cut. The best parameters for material removal rate have been found from Table 2 at level 3 as cutting speed 60 m/min in level 3, feed 0.22 mm/rev in level 3 and depth of cut 1.5 mm in level 3. 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 347.2%.

## REFERENCES

1. Abhang L B and Hameedullah M (2011), "Modeling and Analysis for Surface Roughness in Machining EN-31 Steel using Response Surface Methodology", *International Journal of Applied Research in Mechanical Engineering*, Vol. 1, No. 1, pp. 33-38.
2. Abuelnaga A M and El-Dardiry M A (1984), "Optimization Methods for Metal Cutting", *International Journal of Machine Tool Design and Research*, Vol. 24, No. 1, pp. 11-18.
3. Aman Aggarwal and Hari Singh (2005), "Optimization of Machining Techniques - A Retrospective and Literature Review", *Sadhana*, Vol. 30, No. 6, pp. 699-711.
4. Antony J and Kaye M (1999), "Experimental Quality - A Strategic Approach to Achieve and Improve Quality", *Kluwer Academic Publishers, Dordrecht*.
5. Antony J, Perry D, Wang C and Kumar M (2006), "An Application of Taguchi Method of Experimental Design for New Product Design and Development Process", *Assembly Automation*, Vol. 26, No. 10, pp. 18-24.
6. Ashok Kumar Sahoo, Achyuta Nanda Baral, Arun Kumar Rout and Routra B C (2012), "Multi-objective Optimization and Predictive Modeling of Surface Roughness and Material Removal Rate in Turning using Grey Relational and Regression Analysis", *Procedia Engineering*, Vol. 38, pp. 1606-1627.
7. Basim Khidhir A and Bashir Mohamed (2010), "Study of Cutting Speed on Surface Roughness and Chip Formation when Machining Nickel-based Alloy", *Journal of Mechanical Science and Technology*, Vol. 24, No. 5, pp. 1053-1059.
8. Chryssolouris G and Guillot M (1990), "A Comparison of Statistical and AI Approaches to the Selection of Process Parameters in Intelligent Machining", *ASME-Journal of Engineering for Industry*, Vol. 112, No. 2, pp. 122-131.
9. Chua M S, Rahman M, Wong Y S and Loh H T (2006), "Determination of Optimal Cutting Conditions using Design of Experiments and Optimization Techniques", *Int. J. Mach. Tools Manuf*., Vol. 33, No. 2, pp. 297-305.
10. Ezugwu E O and Okeke C I (2000), "Performance of PVD Coated Carbide Inserts when Machining a Nimonic C-263 Alloy at High Speed Conditions", *Tribology Transaction*, Vol. 43, No. 2, pp. 332-336.

11. Gaitonde V N, Karnik and Paulo Davim (2003), "Multi-performance Optimization in Turning of Free-machining Steel using Taguchi Method and Utility Concept", *Journal of Materials Engineering and Performance*, Vol. 18, No. 3, pp. 231.

12. Gopalsamy B M, Mondal B and Ghosh S (2009), "Taguchi Method and ANOVA: An Approach for Process Parameters Optimization of Hard Machining While Machining Hardened Steel", *Journal of Scientific and Industrial Research*, Vol. 68, pp. 686-695.

13. Haddad M J and Fadaei Tehrani A (2008), "Material Removal Rate (MRR) Study in the Cylindrical Wire Electrical Discharge Turning (CWEDT) Process", *Journal of Materials Processing Technology*, Vol. 199, pp. 369-378.

14. Kadirgama M M, Noor N M, Zuki M M, Rahman M R M, Rejab R, Daud K and Park S H (1996), "Robust Design and Analysis for Quality Engineering", *Chapman & Hall, London*.

15. Kaladhari M and Subbaiah K V (2011), "Application of Taguchi Approach and Utility Concept in Solving the Multi-objective Problem when Turning AISI 202 Austenitic Stainless Steel", *Journal of Engineering Science and Technology Review*, Vol. 4, No. 1, pp. 55-61.

16. Kamal Hassan, Anish Kumar and Garg M P (2012), "Experimental Investigation of Material Removal Rate in CNC Turning using Taguchi Method", *International Journal of Engineering Research and Applications*, Vol. 2, No. 2, pp. 1581-1590.

17. Khorasani A M, Yazdi M R S and Safizadeh M S (2011), "Tool Life Prediction in Face Milling Machining of 7075 Al by Using Artificial Neural Networks (ANN) and Taguchi Design of Experiment (DOE)", *International Journal of Engineering and Technology*, Vol. 3, No. 1, pp. 30-35.

18. Krishankant, Jatin Taneja, Mohit Bector and Rajesh Kumar (2012), "Application of Taguchi Method for Optimizing Turning Process by the Effects of Machining Parameters", *International Journal of Engineering and Advanced Technology*, Vol. 2, No. 1.

19. Liao Y S, Huang J T and Su H C (1997), "A Study on the Machining-parameters Optimization of Wire Electrical Discharge Machining", *Journal of Materials Processing Technology*, Vol. 71, No. 3, pp. 487-493.

20. Liu C H, Andrian C, Chen C A and Wang Y T (2005), "Grinding Force Control in Automatic Surface Finish System", *Journal of Materials Processing Technology*, Vol. 170, pp. 367-373.

21. Lok Y K and Lee T C (xxxx), "Processing of Advanced Ceramics using the Wire-cut EDM Process", *Journal of Materials Processing Technology*, Vol. 63, No. 1-3, pp. 839-843.

22. Metin Kok (2011), "Modeling and Assessment of Some Factors that Influence Surface Roughness for the Machining of Particle Reinforced Metal Matrix Composites", *Arabian Journal for Science and Engineering*, Vol. 36, No. 7, pp. 1347-1365.

23. Mustafa A Y and Ali T (2011), "Determination and Optimization of the Effect of Cutting Parameters and Work Piece Length on the Geometric Tolerances and Surface Roughness in Turning Operation", *International Journal of the Physical Sciences*, Vol. 6, No. 5, pp. 1074-1084.

24. Nian C Y, Yang W H and Tarang Y S (1999), "Optimization of Turning Operations with Multiple Performance Characteristics", *Journal of Material Process Technology*, Vol. 95, pp. 90-96.

25. Park S H (1989), "Robust Design and Analysis for Quality Engineering", *Chapman & Hall, London*.

26. Paulo Davim J (2003), "Design of Optimization of Cutting Parameters for Turning Metal Matrix Composites Based on the Orthogonal Arrays", *Journal of Material processing Technology*, Vol. 132, pp. 340-344.

27. Rao P N (2008), "Manufacturing Technology, Tata McGraw Hill Publication", India.

28. Ross P J (1988), "Taguchi Techniques for Quality Engineering", *McGraw Hill Publishers, New York*.

29. Sanjit Moshat, Saurav Data, Ashish Bandopaddhayay and Pradip Kumar Pal (2010), "Optimization of CNC Milling Process Parameters using PCA Based Taguchi Method", *International Journal of Engineering Science and Technology*, Vol. 2, No. 1, pp. 92-102.

30. Sujit Kumar Jha, Sujit Singh and Shiv Ranjan Kumar (2012), "Experimental Analysis of CNC Turning using Taguchi Method", *Proceedings of Third International Conference on Advances in Mechanical Engineering, Delhi, India, DOI: 02.AETAME*, Vol. 3, No. 15, pp. 91-95.

31. Taguchi G, Choudhary S, and Wu Y (2005), "Taguchi's Quality Engineering Handbook", *John Wiley & Sons Inc., New Jersey*.

32. Taguchi G, El Sayed M and Hsaing C (1989), "Quality Engineering and Production Systems", *New York: McGraw-Hill*.

33. Thamizhmanii S, Saparudin S and Hasan S (2007), "Analysis of Surface Roughness by Turning Process using Taguchi", *Journal of Achievements in Materials and Manufacturing Engineering*, Vol. 20, No. 1-2, pp. 503-506.

34. Yang W H and Tarng Y S (1998), "Design Optimization of Cutting Parameters for Turning Operations Based on the Taguchi Method", *Journal of Materials Processing Technology*, Vol. 84, pp. 122-129.

35. Zhang J Z, Chen J C and Kirby E D (2007), "Surface Roughness Optimization in an End-Milling Operation using the Taguchi Design Method", *Journal of Material Processing Technology*, Vol. 184, pp. 233-239.