Optimization of Material Removal Rate During Turning of SAE 1020 Material in CNC Lathe using Taguchi Technique

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Abstract

In the era of mass manufacturing, MRR (material removal rate) is of primary concern even in manufacturing using contemporary CNC (computer numerical controlled) machines. In this paper Taguchi method has been employed with L25 (5\textsuperscript{3}) Orthogonal Array for three parameters namely Speed, Feed and Depth of cut. For each of these parameters five different levels have been identified and used to perform the turning parameters for maximization of material removal rate on an EMCO Concept Turn 105 CNC lathe. The material selected for machining was SAE 1020 with carbide cutting tool. The MRR is observed as the objective to develop the combination of optimum cutting parameters. This paper proposes an optimization approach using orthogonal array for the maximized MRR and the result from this study confirms the same. This study also produced a predictive equation for determining MRR with a given set of parameters in CNC turning. Thus, with the proposed optimal parameters it is possible to increase the efficiency of machining process and decrease production cost in an automated manufacturing environment.

Keywords: CNC Lathe; Carbide; SAE 1020; MRR, Taguchi; ANOVA.

1. INTRODUCTION

Today, CNC machining has grown to be an indispensible part of machining industry. The accuracy, precision achieved through CNC could not be achieved by the conventional manufacturing machines. But still there is a room for errors in a CNC machine and it basically depends on the skill and experience of the worker to get the dimensions...
right. The machine performance and product characteristics are not guaranteed to be acceptable always. Out of the various parameters which could be considered as the manufacturing goal, the material removal rate (MRR) was considered for the present work as the factor directly affects the cost of machining and the machining hour rate. The machining parameters namely cutting speed, feed rate and depth of cut were considered. The objective was to find the optimized set of values for maximizing the MRR using Taguchi method.

In order to find the optimized set of input parameters and also to identify the effect of each towards a particular output, researchers have been trying for years together. Meng [1] tried to calculate optimum cutting condition for turning operation using a machining theory. Researchers [2-7] have tried to optimize the machining parameters using various methods like Genetic Algorithm, simulated annealing method, Multi-Objective Evolutionary Algorithm etc. Bharathi and Baskar reviewed the researches made on optimization techniques for machining using various mathematical models. Chen [8] tried for optimization of machining conditions for turning cylindrical stocks into continuous finished profiles and Negrete et.al. [9] tried to optimize the cutting parameters for minimizing cutting power where as Cayda [10] tried to vary the cutting tool to evaluate the machinability of AISI 4340 steel.

The Taguchi method emphasizes over the selection of the most optimal solution (i.e. MRR) over the set of given inputs (i.e. cutting speed, feed rate and depth of cut) with a reduced cost and increased quality. The optimal solution so obtained is least affected by any outside disturbances like the noise or any other environmental conditions [11]. Thus, the modern day approach to find the optimal output over a set of given input can be easily carried out by the use of Taguchi method rather than using any other conventional methods. This method has a wide scope of use varying from the agricultural field to medical field and various fields of Engineering sciences. It has been used by many agricultural scientists to evaluate the production of their crops based on the different sets of inputs like the waterfall level, fertility of the land, types of seeds used and many other factors. It is also used by the weather department in forecasting of the various environmental conditions. And, in the field of Science and Engineering, it is used for obtaining optimal results based on the various engineering inputs. Thus, the Taguchi approach has a wide variety of applications in the different fields because of its easiness and optimized results [12]. However, even being having a lot of advantages, it suffers from a major disadvantage that the results obtained are only relative to the levels selected and do not exactly indicate the effect of entire range of each parameter on the performance characteristic value. They also do not test the output for all the combinations of input variables as the combination selected here is limited. Moreover, another major disadvantage of the Taguchi method is that it is not a dynamic process i.e. it is not concerned with those variables which discretely or continuously change their values from time to time. Thus, it deals with mostly the static variables i.e. variables whose values are not time dependent. Moreover, it deals with designing of the quality rather than improving the quality. Because of this, they are applied in the industries at the early stages only [13]. However, despite of all these disadvantages, it is used widely in the different areas very effectively. To reduce the error while using an increased number of inputs, the orthogonal matrix of Taguchi can be used, which is selected as per the requirements of the person. In this work L25 (5^3) Orthogonal Array was used to obtain optimized economical results. The Taguchi method for the Design of Experiments also emphasizes over the use of Loss function, which is the deviation from the desired value of the quality characteristics. Based on these Loss functions, the S/N ratio for each experimental set is evaluated and accordingly the optimal results are derived. ANOVA is then generated for the results and finally, the confirmations results are obtained between the experimental values and the determined values.

2. EXPERIMENTAL DETAILS

The experiments are performed on CNC lathe selected (EMCO Concept Turn 105). The tool and material selected were carbide and mild steel (SAE 1020) respectively. Three process parameters, as already stated above, Cutting speed (A), Feed rate (B) and Depth of cut (C) were considered in the study. Equally spaced five levels within the operating range of the input parameters were selected for each of the process parameters. Based on Taguchi method, an L25 orthogonal array (OA) which has 25 different experiments at five levels was developed. Table 1 shows the design factors along with their levels.
### 3. Results and Discussions

Taguchi technique [14, 15] is a powerful tool for identification of affect of various process parameters based on orthogonal array (OA) experiments which provides much reduced variance for the experiments with an optimum setting of process control parameters. As referred earlier, in this work L25 orthogonal array was used to carry out the experiments and the experimental results (Table 2) were analyzed using Taguchi method.

| Exp No | Cutting Speed (m/s) (A) | Feed Rate (mm/rev) (B) | Depth of Cut (mm) (C) | MRR (mm/min) | SN ratio (dB) |
|--------|------------------------|------------------------|-----------------------|--------------|--------------|
| 1      | 1                      | 1                      | 1                     | 1165.01      | 61.326567    |
| 2      | 1                      | 1                      | 2                     | 1672.03      | 64.464866    |
| 3      | 1                      | 3                      | 3                     | 2979.31      | 69.482315    |
| 4      | 1                      | 4                      | 4                     | 3575.12      | 71.065815    |
| 5      | 1                      | 5                      | 5                     | 4377.16      | 72.823848    |
| 6      | 2                      | 1                      | 2                     | 1387.69      | 62.845873    |
| 7      | 2                      | 2                      | 3                     | 2217.81      | 66.918498    |
| 8      | 2                      | 3                      | 4                     | 3688.94      | 71.338021    |
| 9      | 2                      | 4                      | 5                     | 4243.18      | 72.553829    |
| 10     | 2                      | 5                      | 1                     | 1731.00      | 64.765963    |
| 11     | 3                      | 1                      | 3                     | 2189.63      | 66.807401    |
| 12     | 3                      | 2                      | 4                     | 3046.68      | 69.676541    |
| 13     | 3                      | 3                      | 5                     | 3965.08      | 71.965047    |
| 14     | 3                      | 4                      | 1                     | 2103.74      | 66.459641    |
| 15     | 3                      | 5                      | 2                     | 2898.44      | 69.24329     |
| 16     | 4                      | 1                      | 4                     | 2452.63      | 67.792641    |
| 17     | 4                      | 2                      | 5                     | 3529.92      | 70.95309     |
| 18     | 4                      | 3                      | 1                     | 1480.18      | 63.406262    |
| 19     | 4                      | 4                      | 2                     | 2953.81      | 69.407656    |
| 20     | 4                      | 5                      | 3                     | 3902.47      | 71.826801    |
| 21     | 5                      | 1                      | 5                     | 2828.23      | 69.030305    |
| 22     | 5                      | 2                      | 1                     | 1625.37      | 64.219047    |
| 23     | 5                      | 3                      | 2                     | 2200.19      | 66.849222    |
| 24     | 5                      | 4                      | 3                     | 3447.70      | 70.750585    |
| 25     | 5                      | 5                      | 4                     | 4492.06      | 73.048918    |

In order to assess the variability of the results within a pre defined range, signal to noise ratio (S/N ratio) analysis was done with MRR as the output. For maximization of MRR the S/N ratio was calculated using larger the better criterion. Since the experimental design is orthogonal, it was possible to separate out the effect of each parameter at different levels. The mean S/N ratio for each level of the factors A, B and C was summarized and shown in Table 3. In addition, the total mean S/N ratio for the 25 experiments was also calculated and has been depicted in Table 3. All the calculations were done using Minitab software [16]. The response table indicates the average of the selected characteristic for each level of the factors. The response table also includes ranks based on Delta statistics, which compare the relative extent of effects. The Delta statistic is calculated as the difference of the highest average and...
the lowest average for each factor. Then the Ranks are assigned based on the Delta values. The software assigns rank 1 to the highest Delta value, rank 2 to the second highest, and so on thereafter. The resulting main effects plots for each of the process parameters have been depicted in Fig. 1.

Table 3. Response table of mean S/N ratio.

| Level | A     | B     | C     |
|-------|-------|-------|-------|
| 1     | 67.83 | 65.56 | 64.04 |
| 2     | 67.68 | 67.25 | 66.56 |
| 3     | 68.83 | 68.61 | 69.16 |
| 4     | 68.68 | 70.05 | 70.58 |
| 5     | 68.78 | 70.34 | 71.47 |
| Delta | 1.15  | 4.78  | 7.43  |
| Rank  | 3     | 2     | 1     |

The total mean S/N ratio = 68.36 dB

Since the main effects plot is plotted between the S/N ratio and the various considered values of the input parameters hence if the line for a particular parameter is near horizontal, it indicates that the parameter has no significant effect in the selected range of values. This also indicates that the parameter for which the line has the highest inclination will have the most significant effect. In this work, it is very much clear from the main effects plot that the parameter C (Depth of Cut) and then parameter B (Feed) had the most significant influence on MRR while parameter A (Cutting Speed) has some or negligible effect. The optimal process parameter combination is the one that yields individual maximum mean S/N ratio and thus the same for maximum MRR is A3B5C5.

ANOVA is a statistical technique which provides important conclusions based on analysis of the experimental data. This technique is very useful for revealing the level of significance of the influence of factor(s) or interaction between factors on a particular response. It segregates the total variability of the response into individual contributions of each of the factors and the error. The results are shown in Table 4. ANOVA determines the ratio between the regression mean square and the mean square error and is termed as F-ratio or variance ratio, since it is also the ratio of variance due to the effect of a factor and variance due to the error term, hence the terminology. The ratio is used to measure the significance of each of the parameters under investigation with reference to the variance of all the terms included in the error term at the desired significance level, \( \alpha \). Standard tabulated values are available for comparison. If the calculated value of the F-ratio is higher than the tabulated value of the F-ratio, then the factor is significant at a desired \( \alpha \) level and vice versa. In general, when the F value increases the significance of
the specific parameter also increases. The ANOVA table (Table 4) shows the percentage contribution of each of the parameters. As discussed earlier for the main effect plots, the same trend can be observed for the various parameters, i.e., the parameter C (Depth of Cut) and B (Feed), had the most significant influence on MRR while parameter A (Cutting Speed) was not significant within the specific experimental range.

Table 4. Results of ANOVA.

| Source | DF | SS   | MS   | F    | Contribution (%) |
|--------|----|------|------|------|------------------|
| A      | 4  | 215852 | 53963 | 0.59 | 0.886202256     |
| B      | 4  | 7303309 | 1825827 | 19.82 | 29.98447508    |
| C      | 4  | 15732457 | 3933114 | 42.7 | 64.59119624    |
| Error  | 12 | 1105350 | 92112 | 4.53812642 |        |
| Total  | 24 | 24356968 | 100  |      | 100              |

In order to ascertain the accuracy of the results generated from the software MINITAB a verification test is required to be performed at the optimal level of process parameters. The estimated S/N ratio, \( \hat{y} \) using the optimal level of the process parameter is calculated using the equation 1 as shown below:

\[
\hat{y} = y_m + \sum (\bar{y}_i - y_m)
\]

Where \( y_m \) is the total mean S/N ratio, \( \bar{y}_i \) is the mean S/N ratio at the optimal level. It was observed that there is fairly reasonable agreement between the estimated S/N ratio (73.45 dB) and actual S/N ratio (74.11 dB).

The parametric analysis had been carried out to study the influences of the input process parameter on MRR in turning process in CNC Lathe. To evaluate the variations of the responses, Contour plots and three-dimensional response surface plots based on the quadratic model were drawn. These plots can also provides further assessment of the relationship between the process parameters and response. The contour and response surface plots for MRR with respect to selected input machining parameters are presented in Fig. 2. In all these three 3D surface plots, one of the three independent variables was held constant, in rotation, at their centre level. From the plots it is clear MRR increases with an increase of Feed and Depth of Cut. This increase becomes more prominent as the value of Feed and Depth of Cu
Fig. 2. (a),(b),(c) Surface and Contour Plots for MRR
To order to check and ascertain the improvement of MRR, the experimentation was once again performed at the values at mid-levels of the process parameters i.e. A3B3C3 and the optimized values i.e. A3B5C5. Table 5 shows the result of the confirmation run for MRR and its comparison with the predicted value. The parametric combination for maximum MRR was observed at A3B5C5, i.e. Cutting Speed 64 m/s, Feed 0.35mm/rev and Depth of Cut 0.3mm. The table also shows that the variation in the results between the experimental and theoretical values is very small which clearly confirms the reproducibility of experimental conclusion.

Table 3. Confirmation table.

| Initial parameters | Optimal Parameters |
|--------------------|--------------------|
|                    | Theoretical | Experimental |
| Level              | A3B3C3       | A3B5C5       |
| MRR                | 2845.83      | 4511.28      |
| S/N ratio (dB)     | 69.08        | 73.45        | 74.11        |

4. Conclusion

In this paper, a study had been carried out to optimize the process parameters viz. Cutting Speed, Feed and Depth of Cut with respect to material removal rate (MRR) in CNC Lathe of SAE 1020 steel using Taguchi method. Also, the effect of process parameters on material removal rate was investigated. L25 orthogonal array was used to conduct the experiments. The analysis showed that Depth of Cut had the most significant effect on MRR followed by Feed. With an increase in Depth of Cut MRR increased in the studied range. Optimum cutting parameter combination was found out for maximum MRR and this study may be useful in computer aided process planning.

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