Optimization of Machining Parameters in CNC Turning Using Firefly Algorithm

Dr. S. Bharathi Raja¹ C. Prem Kumar² G. Gokul Rajasekar³ R. P. Dinesh Prasad⁴

¹²³⁴ Department Of Mechanical Engineering
¹Indra Ganesan College of Engineering, Tiruchirapalli, Tamil Nadu. ²,³⁴Parsutham Institute of Technology & Science, Thanjavur.

Abstract—now a day’s machining is done through various automated machines. One of the widely used machines is CNC. Even though the automated machines are used, the quality of the work is determined by parameters used. The cutting parameters of the CNC machine determine the productivity, surface finish, machining time and other qualities of the product. This study involves the optimization of those cutting parameters. In order to get optimized CNC parameters for a specific tool-work combination, Firefly Algorithm (FA) is used to compute the best parameters based on the experiments conducted on a CNC Turning center. The three cutting parameters are cutting speed (V), feed (f), and depth of cut (d). The practical constraints have been considered during both practical and experimental approaches. The result reveals that FA is very well suited in solving parameters selection problems.

I. INTRODUCTION

Computer Numerical Control (CNC) is one of the most commonly used machines. The machining is done by entering the coded information and cutting parameters. Selecting the optimized parameters to attain efficient machining is very difficult. It has been proved that proper selection of parameters decides the productivity rate and the cost of production per component. The implementation of CNC needs high initial investment, so it is must have better usage of the machine to make a profit. The selection of parameters must be within the range which are taken from the cutting tool catalogue or hand books. After getting the range for cutting parameters, the optimization of parameters within the range is done through optimizing techniques. The various optimization techniques available are Genetic Algorithm (GA), Ant Colony Optimization (ACO), and Particle Swarm Optimization (PSO). In this research work, we have used recently developed algorithms called Firefly Algorithm (FA) for the optimization problem. Our ultimate aim is minimizing machining time and attaining better surface finish. Here in this work, we fixed surface finish of a product and we tried to reduce the machining time in order to increase the production rate. The three parameters were analyzed in various ways to determine the effect of one over the other two.

II. LITERATURE REVIEW

M.S.Chua, M.Rahman, Y.S.Wang and H.T.Loh [1] developed relations between the tool life, cutting force, power consumption and the cutting conditions using multiple regression analysis through factorial design of experiments. Based on the analysis, it was found that the tool life model is dependent on depth of cut while the cutting force and power consumption models are dependent on speed, feed and depth of cut. C.Y.Nian, W.H.Yang and Y.S.Tarn [2] employed orthogonal array, multi-response signal-to-noise ratio and ANOVA to study the performance characteristics in turning operations. Experimental results were provided to illustrate the effectiveness in using Taguchi method. The author concluded that the tool life, cutting force and surface roughness could be improved simultaneously using the proposed approach instead of engineering judgment. C.F.Cheung and W.B.Lee [3] established and evaluated a model-based simulation system for analyzing the surface roughness in ultra-precision diamond turning. The analysis includes the effects of process parameters, tool geometry and relative vibration between the tool and work piece. It was found that the system can accurately predict the surface roughness under various cutting conditions.

B.V.Lee, Y.S.Tarn and H.R.Lii [4] described the use of polynomial network to construct the machining database in turning operation. The relationships between the cutting parameters and the tool life, surface roughness and cutting force were accurately correlated by a self-organizing adaptive modeling technique. Experimental results showed that the machining database has a high accuracy in the prediction of cutting performance in turning operation. J. Paulo Davim and C.A.Conecicano Antonio [5] proposed GA to select optimum cutting conditions in turning and drilling aluminium matrix composites. The obtained results show that machining was perfectly compatible with the cutting conditions for cutting time of industrial interest and in agreement with the optimal machining parameters. Numerical and experimental models based on GA are a matter of scientific interest and large industrial applications. M.Y.Noordin, V.C.Venkatesh, S Sharif, S Elting and A Abdullah [6] presented the findings of an experimental investigation of the effect of feed rate, Side Cutting Edge Angle (SCEA) and cutting speed on the surface roughness and tangential force in turning steel. ANOVA revealed that feed is the most significant factor influencing the surface roughness followed by SCEA, while cutting speed provided secondary contribution to the tangential force. The quadratic model developed using RSM was reasonably accurate and can be used for prediction of performance measures. Wassilia Bouzid [7] developed empirical models for tool life, surface roughness and cutting force for calculating optimum cutting conditions in turning to achieve maximum production rate. The coefficients of these models were determined based on the experiments. The author explained the relation of feed to the roughness, which depends on cutting speed and finally concluded that the proposed
Optimization Of Machining Parameters In CNC Turning Using Firefly Algorithm
(IJSRD/ Vol. 2/ Issue 01/ 2014/ 014)

method was capable of selecting the appropriate conditions. Muthukrishnan and J Paulo Davim [8] studied the surface roughness of composite bars under different cutting conditions. Experimental data were tested with ANOVA and ANN techniques. ANOVA revealed that feed rate has highest influence (51%) on surface roughness followed by depth of cut (30%) and cutting speed (12%). The results of ANN model showed close matching between the model output and the directly measured surface roughness. S Bharathi Raja and N Baskar [9] examined SA, GA, and PSO in three different mathematical models such as single pass turning operation, multi-pass turning operation and grinding operation. The authors found that PSO outperformed the other optimization techniques in all the cases. Bharathi Raja and N Baskar [10] adopted PSO for optimize machining parameters to get desired surface roughness in minimum possible machining time. The author’s claimed that average deviation and accuracy rate of predicted surface roughness to the actual surface roughness value is found to be 0.05 microns and 85% respectively. The average deviation and accuracy rate of the predicted machining time to the actual machining time is found to be 2 s and 96% respectively. S.Bharathi Raja, C.V.Srinivas Pramod, K.Vamshee Krishna, Arvind Raganathan and Somalaraju Vinesh [11] implemented Firefly Algorithm (FA) to explore optimum Electric Discharge Machine (EDM) parameters to minimize machining time for the desired surface finish. It is observed that the proposed FA could predict the set objective function considerably close to the experimental values. Bharathi Raja and Baskar [12] conducted face milling experiments on brass material to study the effect of cutting parameters on machining time and surface roughness. PSO has been used in the developed mathematical model for optimization. Confirmatory experiments reveal that PSO could predict optimum cutting parameters very close to the experimental values. Xin-She Yang [13] developed and described a new heuristic optimization technique named as Firefly Algorithm (FA). The results of the developed FA depicts that it is very much suitable for any engineering optimization as it outperformed the proven and most efficient Particle Swarm Optimization (PSO) technique.

III. PILOT EXPERIMENT

In pilot experiments, LL-20-T CNC is used to machine SS 316 material using three different tools for three different machining operations. Fig. 3.1 and Fig. 3.2 shows the raw material and CNC machine used for pilot experiments. The cutting parameters are selected based on the operating range of the machine.

Table 1: Experimental results of machining time for the given parameters of roughing operation.

<table>
<thead>
<tr>
<th>Experiment number</th>
<th>Speed (rpm)</th>
<th>Feed (mm/min)</th>
<th>Depth of cut (mm)</th>
<th>Machining time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>900</td>
<td>0.16</td>
<td>0.8</td>
<td>316</td>
</tr>
<tr>
<td>2</td>
<td>900</td>
<td>0.18</td>
<td>0.8</td>
<td>281</td>
</tr>
<tr>
<td>3</td>
<td>900</td>
<td>0.22</td>
<td>0.8</td>
<td>233</td>
</tr>
<tr>
<td>4</td>
<td>900</td>
<td>0.24</td>
<td>0.8</td>
<td>203</td>
</tr>
<tr>
<td>5</td>
<td>1100</td>
<td>0.16</td>
<td>0.8</td>
<td>259</td>
</tr>
<tr>
<td>6</td>
<td>1100</td>
<td>0.18</td>
<td>0.8</td>
<td>232</td>
</tr>
<tr>
<td>7</td>
<td>1100</td>
<td>0.22</td>
<td>0.8</td>
<td>191</td>
</tr>
<tr>
<td>8</td>
<td>1100</td>
<td>0.24</td>
<td>0.8</td>
<td>174</td>
</tr>
<tr>
<td>9</td>
<td>1500</td>
<td>0.16</td>
<td>0.8</td>
<td>196</td>
</tr>
<tr>
<td>10</td>
<td>1500</td>
<td>0.18</td>
<td>0.8</td>
<td>174</td>
</tr>
<tr>
<td>11</td>
<td>1500</td>
<td>0.22</td>
<td>0.8</td>
<td>146</td>
</tr>
<tr>
<td>12</td>
<td>1500</td>
<td>0.24</td>
<td>0.8</td>
<td>133</td>
</tr>
<tr>
<td>13</td>
<td>1800</td>
<td>0.16</td>
<td>0.8</td>
<td>164</td>
</tr>
<tr>
<td>14</td>
<td>1800</td>
<td>0.18</td>
<td>0.8</td>
<td>147</td>
</tr>
<tr>
<td>15</td>
<td>1800</td>
<td>0.22</td>
<td>0.8</td>
<td>122</td>
</tr>
<tr>
<td>16</td>
<td>1800</td>
<td>0.24</td>
<td>0.8</td>
<td>113</td>
</tr>
</tbody>
</table>

Table 2: Experimental results of machining time for the given parameters of semi-finishing operation.

<table>
<thead>
<tr>
<th>Experiment number</th>
<th>Speed (rpm)</th>
<th>Feed (mm/min)</th>
<th>Depth of cut (mm)</th>
<th>Machining time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1400</td>
<td>0.09</td>
<td>0.2</td>
<td>84</td>
</tr>
</tbody>
</table>

The experiments are conducted for roughing, semi-finishing and finishing operations and their corresponding machining time are observed. Factorial experimentation is adopted in selecting the combination of parameters, in which all the parameters are tested at least once. Table 1-3 shows the machining time for roughing, semi-finishing and finishing operations and their corresponding given cutting parameters.

All rights reserved by www.ijsrd.com 57
A. CNC Parameters

Optimization of cutting speed, feed and depth of cut was selected because requirements in any change in the cutting parameters do not involve time and cost. Among the three parameters, two parameters V and f contribute more on production time. Depth of cut (d) remains same for the complete machining of single operation, but it varies accordingly to the rough, semi-finish and finishing operations. The cutting parameter limits are chosen based on the operating range of work piece and machine capability.

B. Constraints Considered

There are always some practical constraints that exist in actual machining operations. Upper and lower limits of V and f are considered as practical constraints. Equations for the constraints considered are given in equations (1) and (2). Here the depth of cut is kept at the desired value in order to get the required dimension at the end.

\[ V_{\text{min}} \leq V \leq V_{\text{max}}, \]  
\[ f_{\text{min}} \leq f \leq f_{\text{max}}. \]

C. Empirical relation

The empirical relation between the cutting parameters and the machining time for considering these three machining operations are generated using Minitab 16 software. Empirical relations for roughing, semi-finishing and finishing operations are generated in equation (3), (4) and (5).

\[ t_r = 1060.31 - 0.55V + 3332.49f + 3333.33f^2 + 0.79Vf \]  
\[ t_s = 261.11 - 0.07V - 1686.50f + 4062.50f^2 + 0.16Vf \]  
\[ t_f = 737.8 - 0.4V - 4846.2f + 12708.3f^2 + 0.9Vf \]

V. FIREFLY ALGORITHM

Firefly algorithm (FA) was developed by Xin-She Yang. FA is based on the intensity of the light produced by the fireflies. The light was produced by the mechanism called ‘bioluminescence’. The light intensity is the key to selecting the prey for sexual contact; it also acts as a shield from enemies. The fireflies will keep moving until it identifies a better light from a firefly to meet its objective. This concept was used to develop in the proposed optimization techniques. Optimization of input parameters will be iterated until the best solution is attained. Programming for the algorithm was done using JAVA.

A. Population Initiation

The value of V and f are calculated randomly using the equations (6) and (7)

\[ V = V_{\text{min}} + (V_{\text{max}} - V_{\text{min}}) \text{rand}(), \]  
\[ f = f_{\text{min}} + (f_{\text{max}} - f_{\text{min}}) \text{rand}(). \]

B. Distance

\[ x_i \] and \[ x_j \] are the points of presence of two fireflies i and j respectively. The distance \( r_{ij} \) between these two fireflies are represented in terms of Cartesian equation given in equation (8), where \( k \) is the \( k^{th} \) component of \( i^{th} \) firefly and \( d \) is the dimension

\[ r_{ij} = \sum_{k=1}^{d} (x_{ik} - x_{jk})^2. \]
C. Attractiveness equation

Firefly algorithm is based on the attractiveness of the fireflies. The attractiveness function is given in equation (9). In that r is the distance between two fireflies, \( \beta_0 \) is the initial attractiveness at \( r=0 \) and \( \gamma \) is a coefficient which controls the light’s intensity. M is considered as a higher light intensity and it is vice versa to attractiveness. In this article, m is taken as 1 to solve the problem in worst case condition.

\[
\beta = \beta_0 e^{\frac{-\gamma r^m}{m}} \tag{9}
\]

Where \( m \geq 1 \)

D. Movement

The movement of the firefly i towards j due to the attractiveness through the brightness can be given as in equation (10) and (11).

\[
i_{np} = [i \cdot (1 - \beta)] + [i \cdot \beta] + [\alpha \cdot rand() - 0.5] \tag{10}
\]

Similarly for the other firefly,

\[
j_{np} = [j \cdot (1 - \beta)] + [j \cdot \beta] + [\alpha \cdot rand() - 0.5] \tag{11}
\]

Based on the empirical relations formulated by Design Expert software, optimization of cutting parameters to attain minimum machining time is executed by the proposed FA. 1000 iterations with population as 100 are considered for optimization by JAVA programming. After satisfying the considered constraints, optimized cutting parameters are obtained for the minimum possible machining time. The results of optimization are given in table (4), (5) and (6).

<table>
<thead>
<tr>
<th>Speed (rpm)</th>
<th>Feed (mm/min)</th>
<th>Depth of cut (mm)</th>
<th>Machining time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1342</td>
<td>0.20</td>
<td>0.8</td>
<td>160</td>
</tr>
</tbody>
</table>

Table 4: Optimized parameters and its corresponding minimized machining time for roughing operation

<table>
<thead>
<tr>
<th>Speed (rpm)</th>
<th>Feed (mm/min)</th>
<th>Depth of cut (mm)</th>
<th>Machining time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2180</td>
<td>0.13</td>
<td>0.2</td>
<td>21</td>
</tr>
</tbody>
</table>

Table 5: Optimized parameters and its corresponding minimized machining time for semi-finishing operation

<table>
<thead>
<tr>
<th>Speed (rpm)</th>
<th>Feed (mm/min)</th>
<th>Depth of cut (mm)</th>
<th>Machining time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1862</td>
<td>0.09</td>
<td>0.2</td>
<td>49</td>
</tr>
</tbody>
</table>

Table 6: Optimized parameters and its corresponding minimized machining time for finishing operation

VII. RESULTS AND DISCUSSION

Results of pilot experiment have revealed the effect of cutting parameters on machining time. Fig. 7.1 shows the contour plot showing the combined effect of cutting speed and feed on machining time. As speed and feed increase machining time decreases in which machining is more sensitive to feed when compared to speed.

![Contour Plot](image1)

Fig. 3: Contour plot for spindle speed (rpm) Vs feed rate (mm) in roughing operation.

Fig. 3 shows the surface plot showing the combined effect of cutting speed and feed on machining time. The dominating effect of feed on machining time is very well revealed in the plot.

![Surface Plot](image2)
Fig. 4: Surface graph for spindle speed (rpm) Vs feed rate (mm) in roughing operation.

Similarly, the combined effect of speed and feed on machining time in semi-finishing operation is shown in Fig. 5. The effect of feed is comparatively more than cutting speed in machining time.

Fig. 5: contour graph for spindle speed (rpm) Vs feed rate (mm) in semi-finishing operation

Fig. 6 shows the surface plot of the combined effect of speed and feed on machining time in semi-finishing operation.

Fig. 6: Surface graph for spindle speed (rpm) Vs feed rate (mm) in semi-finishing operation

Fig. 7 shows the contour plot drawn to depict the combined effect of speed and feed on machining time.

Fig. 7: Contour graph for spindle speed (rpm) Vs feed rate (mm) in finishing operation

Fig. 8 shows the surface plot of combined effect of speed and feed on machining time in finishing operation. Increase in feed decrease machining time, but the finish of the component comparatively low.

Fig. 8: Surface graph for spindle speed (rpm) Vs feed rate (mm) in finishing operation

From table (4), (5), (6) and table (7), (8),(9), it is evident that the predicted machining time by FA is closer agreement with the actual machining time obtained from confirmatory experiments.

Fig. 9: Comparison of predicted and actual machining time

VIII. CONCLUSION

In this research article, pilot experiments are conducted to study the effect of cutting parameters on machining time for a continuous finished profile. Further, predicted machining time based on cutting parameter optimization by Firefly algorithm was verified by experimental results. The followings are the observations evolved from the present research work:

1) The effect of feed on machining time was dominating more than cutting speed.

2) Firefly algorithm could able to predict the machining time for the proposed continuous profile in terms of accuracy as follows:
   Roughing: 95.2%
   Semi-finishing: 91.3%
   Finishing: 94.2%

3) Firefly algorithm has proved to be one of the best tools for optimization for solving any engineering problems.

4) The present method of selection of cutting parameters can very well be replaced by the proposed method of selection of optimized cutting parameters by FA.

5) Since a real time job profile was undertaken, optimized parameters by FA have increased the production rate
when compared to the parameters utilized before optimization.

6) Time and cost is not a major function in introducing the proposed method of parameters selection.

7) Use of FA is completely generalized and it can be very well used for solving any engineering problems.

8) FA can be interfaced with any CNC machine for online selection of cutting parameters.

A. Scope for future work

In the present work, optimization was performed by considering three parameters. But, the inclusion of other machining parameters may enhance the required results. Moreover, conflicting objectives such as surface roughness, cutting force, tool life can be included as objectives or for the prediction of the same.

REFERENCES


