Optimization of Turning Parameters Using Taguchi’s Method and Artificial Bee Colony Algorithm

Yadnyesh Bhor, Nikhil S Kakuste, Shreyash Gaynar
U.G. Student, Savitribai Phule Pune University, Pune, Nashik, India

Email Address; shreyashag7@gmail.com

Abstract Manufacturing industries are in need of various methods for obtaining the specified output parameters of a product. To fulfil such parameters in accordance to the specification, it is essential to quantitatively analyse the effect of each and every input functions on the output characteristics of the product. With ever increasing customer requirement in functionality and service of a product economically with predetermined quantity CNC machines are now finding application in majority of the industries to get further and better output on demand. In CNC machine, spindle speed, feed and depth of cut are most significant controllable parameters which majorly define the output characteristics of product like surface finish. Industries are now more interested in trends of optimization and automation which ease the process of overcoming constraints. This paper presents experimental study of such parameters of CNC turning centre to optimize the effect of cutting parameters on surface finish of mild steel material. The paper also illustrates how Artificial Bee Colony technique of optimization was used to achieve the results. The experiment is designed and performed by using concept of Design of Experiments (DOE).

Keywords: Artificial Bee Colony technique, Design of Experiments (DOE), Taguchi’s Method
1. INTRODUCTION

A good understanding of machining process and its parameters is essential for evaluating the desired output parameters. While machining any workpiece the input parameters need to be selected in such a manner that their combination as a cumulative effort will result in the best obtainable output. The development of manufacturing technologies to improve machining and obtain high productivity has become a very important goal in modern industry. The challenge of modern machining industries is mainly focused on the achievement of high quality, in terms of workpiece dimensional accuracy, surface finish, high production rate, less wear of the cutting tools, economy of machining in terms of cost saving and increase the performance of the product with reduced environmental impact. Quality in the form of surface finish is the most important criteria in many fields and it plays great importance in evaluating machining parameters. While inspecting the finished surface of the product some major considerations are regarding the tool marks that are left behind, the maximum distance between the peak and valley along with the surface texture. In case of turning operation, the workpiece is rotated by the spindle at a given speed and the turning tool is advanced to take a depth of cut. Once the desired depth of cut is achieved, feed is given to the tool parallel to the spindle axis. The combination of speed of rotation, feed and depth of cut act as input parameters for the machine while performing turning operation. In order to establish an adequate functional relationship between the responses (such as surface roughness, cutting force, tool life/wear) and the cutting parameters (cutting speed, feed, depth of cut, nose radius, cutting time, etc.), a large number of tests are needed, requiring a separate set of tests for each and every combination of cutting tool and workpiece material.

The paper deals with obtaining a functional relationship amongst input parameters that are speed, feed and depth of cut and output parameter surface roughness using linear and non-linear modes of regression analysis along with utilization of Taguchi’s Method. The regression analysis will provide the ability to fit a curve for set of equations obtained by regression analysis. The fitness of the curve with respect to the equations are determined by correlation coefficient, the higher the value of correlation coefficient more is its suitability of fit. The equation of curve will act as an objective function for surface roughness. As the ultimate objective is to maximize the surface finish, minimization of surface roughness will be performed using Design of Experiments (D.O.E) method and Evolutionary optimization algorithm that are gradient free in nature to avoid local minima.

There are two objectives of this seminar study, to obtain optimal process parameters for a turning mild steel workpiece on DX200-4B CNC turning machine by using a carbide cutting tool type TNMG 160408. The first is to apply Taguchi’s method for D.O.E. to find out the best possible combination for turning a Mild Steel component. The second is to demonstrate the use of Artificial Bee Colony optimization method in order to find out the optimum surface roughness with a particular combination of cutting parameters in a turning operation by multimodal type of objective optimization.

1.1 Introduction to CNC machine: -

The introduction of CNC machine radically changed the manufacturing industry to produce complex curved profile as easy to cut as straight lines and also easy to produce intricate structures. With
improved automation techniques of manufacturing processes and reduction on dependency of human operators led to development of CNC machines. These machines resulted into improvement over machine control, machine capacity and machine capability as well as the quality of the finished product. In CNC turning surface finish is the important factor that is significantly influenced by machining performance. CNC machines are capable of achieving reasonable accuracy, surface finish and very low processing time as compared to the conventional machine. Figure 1 shows the block diagram of the working principle of CNC machine.

![Figure 1 Block Diagram of CNC Machine](image)

1.2 Introduction to Turning:
Turning is a machining operation wherein material is removed from the outer periphery of the workpiece, resulting in reduction of diameter of the workpiece. Generally, turning operation is most widely performed on Lathe machines and hence they are also termed as Turning Machine. This study has considered three machine tool parameters: Spindle Speed for 4 levels and Feed, Depth of Cut for 3 levels.
Figure. 2. Turning operation [4]

2. LITERATURE REVIEW

| Sr. No. | Year | Author | Material | Input Parameters | Output Parameter | Method | Significant Parameter |
|---------|------|--------|----------|------------------|------------------|--------|-----------------------|
| [1]     | 2013 | Mussa I. Mgwatu | Low Carbon Steel | Cutting Speed, Feed, DOC | Cycle Time, Production Cost | Lingo Non-Linear Software Package | Feed |
| [2]     | 2014 | Sayak Mukherje, Anurag Kamal, Kaushik Kumar | SAE 1020 | Speed, Feed, DOC | Material Removal Rate | Taguchi Technique of Orthogonal Array | DOC, Feed |
| [3]     | 2011 | Weifeng Gao, Sanyang Liu, Liuling Huang | - | No. of bees, search zone, objective function, constraint | Optimize d solution | Artificial Bee Colony | Operation characteristics of bees are mimicked |
| [4]     | 2014 | Jitendra Thakkar | SS 410 | Cutting Speed, Feed, DOC | Surface Roughness and Material Removal Rate | ANOVA Method | Feed, DOC |
| [5]     | 2015 | Krupal Pawar and R. D. Palhade | High Speed Steel (M2) | Insert Nose Radius, Cutting Speed, Feed, DOC | Surface Roughness | Taguchi Technique and ANOVA Analysis | Feed Rate and Nose Radius |
Mussa I. Mgwatu in his paper on “Machining Optimization and Operation allocation for NC lathe machines in a job shop manufacturing system” explains the economics of a manufacturing process in relation to the various types of times that are encountered during the machining operation. If the cycle time is minimized with the production time equal to cycle time, then slack times among machines can totally be eliminated. The study has also confirmed that if the minimized cycle time is treated as the constraint in the production cost model, then the production cost can further be reduced. The objective is solved for effective assignment of cutting operations for each machine and optimal cutting speed, feed rate, depth of cut for all rough and finish operations for different part features. [1]

Sayak Mukherje, Anurag Kamal, Kaushik Kumar in their paper on “Optimization of Material Removal Rate During Turning of SAE 1020 Material in CNC Lathe using Taguchi Technique” elaborate the Taguchi technique as 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. [2]

Weifeng Gao, Sanyang Liu, Lingling Huang in their journal paper “A global best artificial bee colony algorithm for global optimization” explain the algorithm wherein a candidate source position that is produced and evaluated by the artificial bee, its performance is compared with that of the old one. If the new food source has a better quality of nectar amount the bees gather along it revising its source position. The number of cycles for which the bees will explore and exploit will depend on a predetermined number also called as the abandonment of bees from further exploration. [3]

Jitendra Thakkar, Mitesh Patel in their research article “A Review on Optimization of Process Parameters for Surface Roughness and Material Removal Rate for SS 410 Material During Turning Operation” investigated the effects of process parameters feed, speed, depth of cut and nose radius on surface finish and material removal rate (MRR) to obtain the optimal setting of these process parameters. The aim of experimental investigation is to evaluate the effects of the process parameters
on AISI 304 austenitic stainless-steel work piece surface roughness and material removal rate by employing Taguchi’s orthogonal array design and Analysis of Variance (ANOVA) using PVD coated Cermets tool on CNC lathe under dry environment. They conclude that most effected parameters to cutting condition are cutting speed, feed rate and depth of cut and they are easily controlled by operator at the machine at same time or simultaneously. [4]

Krupal Pawar, R. D. Palhade in their journal paper” Multi-objective Optimization of CNC Turning Process Parameters for High Speed Steel (M2) Using Taguchi and ANOVA Method” determine the best design required for the use of a designed experiment. According to them Taguchi converts the objective function values to Signal-to-Noise ratio (S/N ratio) to measure the performance characteristics of the levels of control factors that affect the entire parametric space with a limited number of experiments. The four machining parameters considered in this study are cutting speed, feed rate, depth of cut, and insert nose radius. [5]

G. Harinath Gowda, M. VenugopaGoud, K. DivyaTheja, M. Gunasekhar Reddy I their journal paper ” Optimal Selection Of Machining Parameters In CNC Turning Process Of EN-31 Using Intelligent Hybrid Decision Making Tools”, explain the three main variables that affect the formation of the chips in cutting are the tool geometry, work and tool materials. The interaction between the tool and work material is also significant: this is often mentioned as the fourth main variable. All the above variables are tested for different network configurations, as per the value of performance error obtained, best model is identified and selected. The models are evaluated by calculating the percentage deviation using predicted values and actual values.[6]

M. Kaladhar, K. VenkataSubbaiah, C. Srinivas Rao, K. Narayana Rao in their journal paper” Optimization of process parameters in Turning of AISI202 austenitic stainless steel” have observed a slight inclination of significance in case of interaction between speed and nose radius to influence surface roughness when compared with other interactions. These results are analyzed using ANOVA for the purpose of identifying the significant factors, which affects the surface roughness. [7]

3. PROBLEM STATEMENT & OBJECTIVES OF STUDY: -

Optimization of turning parameters is usually a complex task where the aspects such as domain knowledge of machining and the specification of machine tool capabilities is mandatory. The level of selection of input parameters is calculated on the basis of threshold value that signify the major difference of output response amongst the consecutive levels and determine the range of optimization. In a turning operation, it is important task to select the best combination of parameter levels for achieving high cutting performance i.e. surface roughness. The main aim of study is to find the optimal values of input machine parameters to get minimum surface roughness. Following are the objectives of the study:

1. To study the optimization and optimization technique.
2. To study the working of CNC machine parameters and their effects on output parameter.
3. To study regression modelling of experimental data in the form of linear or nonlinear regression form.
4. To establish the relationship equation between Surface Roughness and process parameters.
5. To obtain the optimum value of machine parameters to get global optimum result of output parameter i.e. Surface Roughness.

3.1 PARAMETER SELECTION: -
3.1.1 SELECTION OF MACHINE PARAMETERS: -

1. Speed: -
   Speed always refers to the spindle and the work piece. When it is stated in revolutions per minute (rpm) it tells their rotating speed.

2. Feed: -
   Feed always refers to the cutting tool, and it is the rate at which the tool advances along its cutting path. On most power-fed lathes, the feed rate is directly related to the spindle speed and is expressed in mm (of tool advance) per revolution (of the spindle), or mm/rev.

3. Depth of Cut: -
   Depth of cut is the thickness of the layer being removed (in a single pass) from the work piece or the distance from the uncut surface of the work to the cut surface, expressed in mm. It is important to note that the diameter of the work piece is reduced by two times the depth of cut because this layer is being removed from both sides of the work.
   \[ \text{Depth of cut} = \frac{D_0-D_1}{2} \text{ mm} \]
   Here, \( D_0 \) and \( D_1 \) represent initial and final diameter (in mm) of the job respectively.

3.1.2 RESPONSE PARAMETER: -

- Surface Roughness: -
   Roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small the surface is smooth. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface. Surface roughness is an important measure of product quality since it greatly influences the performance of mechanical parts as well as production cost. Surface roughness has an impact on the mechanical properties like fatigue behavior, corrosion resistance, creep life, etc. surface roughness tester to measure surface roughness of work piece

3.2 EFFECT ON OUTPUT PARAMETER: -

3.2.1. EFFECT OF INDIVIDUAL PARAMETER ON SURFACE ROUGHNESS (Ra): -

1. Spindle Speed: - Spindle speed is a significant parameter in the turning operation of CNC machine. It has a sizeable influence on the surface roughness of turning operation. As the spindle speed increases surface roughness also increases.
2. Feed: Feed has the maximum influence on the surface roughness. As the feed increases, the surface roughness also increases.

3. Depth of Cut (DOC): Depth of Cut has the second most influence on Surface Roughness after feed. As the Depth of Cut increases surface roughness also increases.
3.3 SELECTION OF LEVELS OF PARAMETERS

Table 2: Levels of Parameters [10]

| Cutting parameters | Designation | Units   | Operational range | Level 1 | Level 2 | Level 3 | Level 4 |
|--------------------|-------------|---------|-------------------|---------|---------|---------|---------|
| Spindle speed      | N           | RPM     | 900-3600          | 900     | 1800    | 2700    | 3600    |
| Feed               | F           | mm/rev  | 0.1-0.8           | 0.1     | 0.45    | 0.8     | -       |
| Depth of cut       | D           | mm      | 0.5-1.0           | 0.5     | 0.75    | 1.0     | -       |

Table 3: Range of Parameters [10]

| CUTTING PARAMETERS | RANGE          |
|-------------------|----------------|
| Spindle speed     | 50-4000 RPM    |
| Feed              | 0.1-0.8 mm/rev |
| Depth of cut      | 0.1-1.5 mm     |
4. CASE STUDY:

4.1 EXPERIMENTAL DATA:

This experimental data is obtained by performing full factorial Design of Experiment (DOE).

Table 4: Experimental Data after S/N Processing

| Sr. No. | Expt. No. | Spindle Speed | Feed | Depth of Cut | Surface Roughness | S/N Ratio |
|---------|-----------|---------------|------|--------------|-------------------|-----------|
|         |           | $x_1$ (RPM)   | $x_2$ (mm/rev) | $x_3$ (mm) | $Y_1$ (µm)       |           |
| 1.      | E-1       | 900           | 0.1  | 1            | 0.282             | -10.995   |
| 2.      | E-2       | 900           | 0.1  | 0.75         | 0.261             | -11.6672  |
| 3.      | E-3       | 900           | 0.1  | 0.5          | 0.33              | -9.62972  |
| 4.      | E-4       | 900           | 0.45 | 1            | 1.855             | 5.366878  |
| 5.      | E-5       | 900           | 0.45 | 0.75         | 1.93              | 5.711146  |
| 6.      | E-6       | 900           | 0.45 | 0.5          | 1.827             | 5.234771  |
| 7.      | E-7       | 900           | 0.8  | 1            | 2.404             | 7.618689  |
| 8.      | E-8       | 900           | 0.8  | 0.75         | 2.428             | 7.704974  |
| 9.      | E-9       | 900           | 0.8  | 0.5          | 2.332             | 7.317244  |
| 10.     | E-10      | 1800          | 0.1  | 1            | 0.542             | -5.32001  |
| 11.     | E-11      | 1800          | 0.1  | 0.75         | 0.555             | -5.11414  |
| 12.     | E-12      | 1800          | 0.1  | 0.5          | 0.189             | -14.4708  |
| 13.     | E-13      | 1800          | 0.45 | 1            | 2.051             | 6.239313  |
| 14.     | E-14      | 1800          | 0.45 | 0.75         | 2.001             | 6.024942  |
| 15.     | E-15      | 1800          | 0.45 | 0.5          | 2.011             | 6.068241  |
| 16.     | E-16      | 1800          | 0.8  | 1            | 2.628             | 8.569175  |
| 17.     | E-17      | 1800          | 0.8  | 0.75         | 2.433             | 7.722842  |
| 18.     | E-18      | 1800          | 0.8  | 0.5          | 2.469             | 7.850422  |
| 19.     | E-19      | 2700          | 0.1  | 1            | 1.39              | 2.860296  |
4.2 METHODOLOGY: -

4.2.1 Taguchi’s Method for D.O.E.

The method states that the amount of experiments required to perform in accordance to full factorial design method are generally not feasible due to its large population. To overcome this only a certain amount of experiments is needed so as to imitate the same effect as that obtained from full factorial design method. The limited number of experiments to be performed in a preset combination to deliver the same flavor as Full Factorial Design method are evaluated as per Taguchi’s Orthogonal Array. Although as the full factorial design of experiments is already available for a combination 4 levels of speed, and 3 levels of fed and depth of cut as variables from [14] the number of experiments that have been performed are 36. Therefore, proceeding further calculations in accordance to Taguchi’s method for D.O.E.

Post the conduction of experiments, a Signal to Noise ratio is calculated the S/N ratio estimates the effect of Desirable controllable parameters with respect to Undesirable non-controllable parameters. In case of the experiment the desirable controllable parameters are speed, feed and depth of cut respectively, whereas the undesirable and non-controllable parameters are stiffness of spindle, degree of vibration, etc.

The objective function of the study is Surface Roughness (Ra value), it is essential to minimize the objective function so as to obtain the maximum surface finish. This is done by substituting the value of S/N ratio as:

| Experiment | Speed | Feed | Depth of Cut | S/N Ratio |
|------------|-------|------|--------------|-----------|
| 20. E-20   | 2700  | 0.1  | 0.75         | 1.233     | 1.819262 |
| 21. E-21   | 2700  | 0.1  | 0.5          | 0.199     | -14.0229 |
| 22. E-22   | 2700  | 0.45 | 1            | 1.998     | 6.01191  |
| 23. E-23   | 2700  | 0.45 | 0.75         | 1.969     | 5.844914 |
| 24. E-24   | 2700  | 0.45 | 0.5          | 2.034     | 6.167019 |
| 25. E-25   | 2700  | 0.8  | 1            | 2.596     | 8.286094 |
| 26. E-26   | 2700  | 0.8  | 0.75         | 2.546     | 8.117168 |
| 27. E-27   | 2700  | 0.8  | 0.5          | 2.562     | 8.171583 |
| 28. E-28   | 3600  | 0.1  | 1            | 1.498     | 3.510236 |
| 29. E-29   | 3600  | 0.1  | 0.75         | 1.322     | 2.424629 |
| 30. E-30   | 3600  | 0.1  | 0.5          | 0.214     | -13.3917 |
| 31. E-31   | 3600  | 0.45 | 1            | 1.981     | 5.93769  |
| 32. E-32   | 3600  | 0.45 | 0.75         | 1.924     | 5.684101 |
| 33. E-33   | 3600  | 0.45 | 0.5          | 1.928     | 5.702141 |
| 34. E-34   | 3600  | 0.8  | 1            | 2.744     | 8.767682 |
| 35. E-35   | 3600  | 0.8  | 0.75         | 2.782     | 8.887143 |
| 36. E-36   | 3600  | 0.8  | 0.5          | 2.729     | 8.720071 |
\[ S = 10 \times \log_{10}(Ra^2) \]

The greater the S/N ratio the greater is the controllability of input machine parameters. For each combination of each level of variables the average of S/N ratio is obtained individually indicated in Table 5, Table 6 and Table 7 for speed, feed, and depth of cut respectively. Once the average of S/N ratio is obtained a relationship matrix is to be developed indicating the average S/N ratio for each level of input parameter i.e. speed, feed and depth of cut, Refer Table 8.

### Table 5: Speed data rearranged in accordance to S/N ratio of individual level

| No. of combinations | s/n1     | s/n2     | s/n3     | s/n4     |
|---------------------|----------|----------|----------|----------|
| Speed level (R.P.M) | 900      | 1800     | 2700     | 3600     |
| 1                   | -10.995  | -5.32001 | 2.860296 | 3.510236 |
| 2                   | -11.6672 | -5.11414 | 1.819262 | 2.424629 |
| 3                   | -9.62972 | -14.4708 | -14.0229 | -13.3917 |
| 4                   | 5.366878 | 6.239313 | 6.01191 |        |
| 5                   | 5.711146 | 6.024942 | 5.884914 | 5.684101 |
| 6                   | 5.234771 | 6.068241 | 6.167019 | 5.702141 |
| 7                   | 7.618689 | 8.569175 | 8.286094 | 8.767682 |
| 8                   | 7.704974 | 7.722842 | 8.117168 | 8.887143 |
| 9                   | 7.317244 | 7.850422 | 8.171583 | 8.720071 |
| Sum                 | 6.661774 | 17.57002 | 33.29531 | 36.24197 |
| Mean                | 0.740197 | 1.952224 | 3.699478 | 4.026885 |

### Table 6: Feed data rearranged in accordance to S/N ratio of individual level

| No. of combinations | s/n1     | s/n2     | s/n3     |
|---------------------|----------|----------|----------|
| Feed level(mm/rev)  | 0.1      | 0.45     | 0.8      |
| 1                   | 7.618689 | 5.366878 | -10.995  |
| 2                   | 7.704974 | 5.711146 | -11.6672 |
| 3                   | 7.317244 | 5.234771 | -9.62972 |
| 4                   | 8.569175 | 6.239313 | -5.32001 |
| 5                   | 7.722842 | 6.024942 | -5.11414 |
| 6                   | 7.850422 | 6.068241 | -14.4708 |
| 7                   | 8.286094 | 6.01191 | 2.860296 |
| 8                   | 8.117168 | 5.884914 | 1.819262 |
| 9                   | 8.171583 | 6.167019 | -14.0229 |
| 10                  | 8.767682 | 5.93769 | 3.510236 |
| 11                  | 8.887143 | 5.684101 | 2.424629 |
| 12                  | 8.720071 | 5.702141 | -13.3917 |
| Sum                 | 97.73309 | 70.03307 | -73.9971 |
| No. of combinations | s/n1   | s/n2   | s/n3   |
|---------------------|--------|--------|--------|
| DOC level (mm)      | 1      | 0.75   | 0.5    |
| 1                   | -10.995| -11.667| -9.62972|
| 2                   | 5.366878 | 5.711146 | 5.234771|
| 3                   | 7.618689 | 7.704974 | 7.317244|
| 4                   | -5.32001| -5.11414| -14.4708|
| 5                   | 6.239313 | 6.024942 | 6.068241|
| 6                   | 8.569175 | 7.722842 | 7.850422|
| 7                   | 2.860296 | 1.819262 | -14.0229|
| 8                   | 6.01191 | 5.884914 | 6.167019|
| 9                   | 8.286094 | 8.117168 | 8.171583|
| 10                  | 3.510236 | 2.424629 | -13.3917|
| 11                  | 5.93769 | 5.684101 | 5.702141|
| 12                  | 8.767682 | 8.887143 | 8.720071|
| Sum                 | 46.85293 | 43.19979 | 3.716343|
| Mean                | 3.904411 | 3.599983 | 0.309695|

Table 7: D.O.C data rearranged in accordance to S/N ratio of individual level

The relationship matrix represents the average S/N ratio of each level of speed, feed and depth of cut. The levels of parameters speed, feed and depth of cut are as indicated in Table 2. For individual parameter level, the difference amongst the greatest and least value for that parameter itself is calculated, indicated in Table 8. The magnitude of difference indicates the significance of that parameter on the objective function. The significance of each parameter on objective function is ranked in accordance to their magnitude of difference amongst the maximum and minimum average S/N ratio, indicated in Table 10.

The result indicates that the effect of feed on surface roughness is maximum followed by depth of cut and speed. The effect of feed on surface roughness is almost five times that of the remaining parameters.

Table 8: Relationship matrix amongst parameters to evaluate rank of significance

| Parameter     | level1   | level2   | level3   | level4   | difference | Rank of significance |
|---------------|----------|----------|----------|----------|------------|----------------------|
| Speed (R.P.M) | 0.74019708 | 1.952224 | 3.699478 | 4.026885 | 3.286688   | 3                    |
| Feed (mm/rev) | -6.166424 | 5.836089 | 8.144424 | 14.31085 | 8.171583   | 1                    |
| DOC (mm)      | 3.90441096 | 3.599983 | 0.309695 | 3.594716 | 0.309695   | 2                    |

Each level of a parameter is ranked in terms of its magnitude of average S/N ratio in Table 8. The overall results obtained indicate that the best level of parameters for machining the workpiece are indicated with red color marking. The cumulative of all the best levels of parameters lead to the best possible combination for turning the workpiece. The best combination is shown on Table 10, along with the resultant Surface Finish.

Table 9: Rank matrix
|      | level1 | level2 | level3 | level4 |
|------|--------|--------|--------|--------|
| Speed| 4      | 3      | 2      | 1      |
| Feed | 3      | 2      | 1      |        |
| Doc  | 1      | 2      | 3      |        |

**Table 10: Result table for D.O.E.**

**BEST COMBINATION**

| Speed (R.P.M) | 3600  |
| Feed (mm/rev) | 0.8   |
| DOC (mm)      | 1     |

RESULTANT Ra= 2.744 micron

4.2.2 Regression Modelling

The experimental matrix that was adopted in this study in the form of actual values is shown in the Table 2. To study the effect of process parameters, i.e. Spindle Speed, Feed, Depth of Cut, on response parameters, i.e. Surface Roughness (R_a), a first order and second-order polynomial response is fitted into the following equation.

Let, \( N = x_1 \),
\( F = x_2 \) &
\( D = x_3 \)

4.2.2.1 Linear Regression

From experimental data, following values are collected:
\[
\begin{align*}
&n = 36, \sum x_1 = 81000, \sum x_2 = 16.2, \sum x_3 = 27, \sum y = 62.2, \sum x_1 x_2 = 36450, \sum x_1 x_3 = 60750, \\
&\sum x_2 x_3 = 12.15, \sum x_1^2 = 218700000, \sum x_2^2 = 10.23, \sum x_3^2 = 21.75, \sum x_1 y = 145328.4, \sum x_2 y = 35.90295, \sum x_3 y = 47.419 \\
&\text{A B = C}
\end{align*}
\]

The matrices were solved on Scilab Software.
\[ R^2 = 87.90\% \]

\[ a_0 = -0.199888, a_1 = 0.0001476, a_2 = 2.69147965, a_3 = 0.5126667 \]

The equation obtained by linear regression is:

\[ Y = (-0.199888) + (0.0001476 \cdot x_1) + (2.69147965 \cdot x_2) + (0.5126667 \cdot x_3) \]

### 4.2.2.2 Non-Linear Regression

From experimental data, following values are collected:
Similarly, by solving on Scilab, we get:

\[ R^2 = 94.80\% \]

\[ a_0 = -1.612, \ a_1 = 0.0001, \ a_2 = 7.135, \ a_3 = 2.547, \ a_4 = -0.0002, \ a_5 = -1.786, \ a_6 = 0.00033, \ a_7 = -2.17 \times 10^{-08}, \ a_8 = -2.840, \ a_9 = -1.317 \]

\[ Y = (-1.612) + (0.0001 \times x_1) + (7.135 \times x_2) + (2.547 \times x_3) + (-0.0002 \times x_1 \times x_2) + (-1.786 \times x_2 \times x_3) + (0.00033 \times x_1 \times x_3) + (-0.000000217 \times x_1 \times x_1) + (-2.84 \times x_2 \times x_2) + (-1.317 \times x_3 \times x_3) \]

As the second order polynomial response for the data has a greater value of co-relation coefficient i.e. \( R^2 \). Therefore, selecting the second order polynomial as response equation to input machine parameters.

\[ y = a_0 + \sum_{i=1}^{p} a_i x_i + \sum_{i=1}^{p} a_{ii} x_i^2 + \sum_{j=1}^{p} a_{ij} x_i x_j \]

Where \( y \) is the response and \( x_i \) are experimental levels of \( p \) quantitative variables. The coefficients \( a_0 \) is the free term, the coefficients \( a_i \) are the linear terms, the coefficients \( a_{ii} \) are the quadratic terms and the coefficients \( a_{ij} \) are the interaction terms. Matrices (A) and (B) are then derived by determining the value of the coefficients using the Cramer's Rule for the observations collected as shown in Table 2, for Surface Roughness (Ry).

4.2.3 Artificial Bee Colony:
In ABC, the colony of artificial bees contains three groups of bees: employed bees associated with specific food sources, onlooker bees watching the dance of employed bees within the hive to choose a food source, and scout bees searching for food sources randomly. Both onlookers and scouts are also called unemployed bees. Initially, all food source positions are discovered by scout bees. Thereafter, the nectar of food sources is exploited by employed bees and onlooker bees, and this continual exploitation will ultimately cause them to become exhausted. Then, the employed bee which was exploiting the exhausted food source becomes a scout bee in search of further food sources once again. In other words, the employed bee whose food source has been exhausted becomes a scout bee. In ABC, the position of a food source represents a possible solution to the problem and the nectar amount of a food source corresponds to the quality (fitness) of the associated solution. The number of employed bees is equal to the number of food sources (solutions) since each employed bee is associated with one and only one food source.

In summary, the ABC algorithm,

i. is inspired by the foraging behaviour of honeybees,

ii. is a global optimization algorithm,

iii. has been initially proposed for numerical optimization,

iv. can be also used for combinatorial optimization problems,

v. can be used for unconstrained and constrained optimization problems,

vi. employs only three control parameters (population size, maximum cycle number and limit) that are to be predetermined by the user,

vii. is quite simple, flexible and robust

Figure 6
Flowchart of A.B.C.
4.3 Results:

The result obtained after using artificial bee colony method, determine that the optimum combination of input parameters Spindle speed, Feed and Depth of cut to be selected are depicted in Table 11. and 12. Table 11 indicates the results obtained from linear type of regression. Table 12 indicates the results obtained using non-linear regression. The optimum combination of all the input parameters would result in a best output surface roughness value of 0.050001 micron.

Table 11: Result Table: Linear Regression

| BEST COMBINATION |             |
|------------------|-------------|
| Speed (R.P.M)    | 50          |
| Feed (mm/rev)    | 0.1         |
| DOC (mm)         | 0.1         |

RESULTANT $Ra = 0.127907$ micron

Table 12: Result Table: Non-Linear Regression

| BEST COMBINATION |             |
|------------------|-------------|
| Speed (R.P.M)    | 2112.225    |
| Feed (mm/rev)    | 0.208031    |
| DOC (mm)         | 0.1         |

RESULTANT $Ra = 0.050001$ micron

[Progress | Action log | Current best solution | Overall best solution]

Objective value: $O V 1 = 5.0000559225E-002$
Spindle Speed: $2112.2250442205$
FEED: $0.208031049326363$
DOC: $0.1$

7 Output window showing final result
5. CONCLUSION:

1. According to Taguchi’s method, the result obtained is best possible combination of desirable input parameters that can be set to obtain minimum surface roughness.
2. The result obtained is viable only when the input parameters operate in the predefined levels. Better surface roughness value is evident in Table 4, although the roughness value indicated has a S/N ratio below par compared to other values.
3. The result of surface roughness(Ra) obtained by Artificial Bee Colony can be defined as the global minima, wherein the best possible parameters combination of Spindle speed, feed and depth of cut required is indicated in Table12.
4. If a comparison is to be made between the results obtained by Taguchi’s Method and that obtained by Artificial Bee Colony method, the improvement in results in percentage is 98.17%. The significant improvement in result can be attributed to the difference of local and global minima that have been obtained while following the numerical methods.
5. This study shows that for the linear regression modelled, the optimum conditions of variable parameters are the combination of lower boundary condition. But for the Non-linear regression it should vary as per initial guess assumed.
6. The study shows that the FEED has the maximum effect on the variable parameter i.e. surface roughness followed by Depth of Cut and Spindle Speed.

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