Optimization of the Machining parameter of LM6 Alminium alloy in CNC Turning using Taguchi method

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Abstract. Due to widespread use of highly automated machine tools in the industry, manufacturing requires reliable models and methods for the prediction of output performance of machining process. In machining of parts, surface quality is one of the most specified customer requirements. In order for manufactures to maximize their gains from utilizing CNC turning, accurate predictive models for surface roughness must be constructed. The prediction of optimum machining conditions for good surface finish plays an important role in process planning. This work deals with the study and development of a surface roughness prediction model for machining LM6 aluminum alloy. Two important tools used in parameter design are Taguchi orthogonal arrays and signal to noise ratio (S/N). Speed, feed, depth of cut and coolant are taken as process parameter at three levels. Taguchi’s parameters design is employed here to perform the experiments based on the various level of the chosen parameter. The statistical analysis results in optimum parameter combination of speed, feed, depth of cut and coolant as the best for obtaining good roughness for the cylindrical components. The result obtained through Taguchi is confirmed with real time experimental work.

1. Introduction
Two important issues in manufacturing process of modeling and optimization. A greater attention is given to accuracy and surface roughness of product by the industry these days. Surface finish has been one of the most important considerations in determining the machinability of materials. The predictive modeling of machining operations requires detailed prediction of the boundary conditions for stable machining. Most surface roughness prediction models are empirical and are generally based on experiments in the laboratory. In addition, it is very difficult in practice; to keep all factors under controls as required obtaining reproducible results. Generally these models have a complex relationship between surface roughness and operational parameters not only increase the utility for machining economics, but also the product quality to a great extent. Column number represents the influencing factor and row number represents the trial number. The other numbers represent the level of the factor represented by their column number.
Optimization process involving seven parameters at two levels. Experiments have been conducted based on the orthogonal array and these data obtained have been analyzed using ANOVA and response curves [1]. Statistical model for surface roughness estimation in a high-speed flat end milling process under wet cutting conditions. The variables taken are spindle speed, feed rate, depth of cut, and step over. This work deals with obtaining parameter settings for both minimum surface roughness and long tool life [2]. Optimized the turning operation with multiple performance characteristics. Taguchi method of optimization was applied to optimize three control factors such as cutting speed, feed rate, and depth of cut considering the performance characteristics such as Tool life, cutting force, surface Roughness which was designed in L9 orthogonal array [3]. Optimal value of cutting force by an optimal setting of turning process parameters while machining En24 alloy steel with TiC coated carbide inserts. The effects of the selected parameters have been accomplished using Taguchi’s parameter design approach. The results indicate that the selected process parameters – speed, feed, and depth of cut, as well as interaction between cutting speed and depth of cut significantly affect the mean and variance of cutting force [4]. Predict the surface roughness of machined parts in the end milling process was developed to assure product quality and increase reproduction rate by predicting the surface finish parameter in real time [6].

2. Orthogonal array
Column number represents the influencing factor and row number represents the trial number. The other numbers represent the level of the factor represented by their column number which is shown in Table 1.

| Table 1. Standard L9 (3^4) Array |
|-----------------------------------|
| Trial number | COLUMN NUMBER |   |
| 1            | 1             | 1 |
| 2            | 1             | 2 |
| 3            | 1             | 3 |
| 4            | 1             | 4 |
| 5            | 2             | 1 |
| 6            | 2             | 2 |
| 7            | 3             | 3 |
| 8            | 3             | 2 |
| 9            | 3             | 1 |

2.1 Details of experiments conducted
Taguchi experiments to identify the optimum surface roughness and to find the percentage contribution of parameters namely speed, feed rate, depth of cut and coolant flow rate shown in Table 2. Taguchi L9(3^4) orthogonal array was used to design the experiments as shown in Table 3.

| Table 2. Variables factor levels |
|----------------------------------|
| Controllable factors            | Level 1 | Level 2 | Level 3 |
| Depth of cut (mm)               | 0.4     | 0.6     | 0.8     |
| Spindle speed (rpm)             | 1400    | 2000    | 2600    |
| Feed (mm)                       | 0.05    | 0.15    | 0.25    |
| Coolant flow rate (lit/sec)     | 0.02    | 0.05    | 0.1     |

| Table 3. Orthogonal array L9 (3^4) |
3. Results and discussion
The results of the experiments for nine trials conditions with three measurement locations the average response values and the S/N ratio were recorded in Table 4.

Table 4. Result of the $L_9\left(3^4\right)$ experiment

| Exp. no | Depth of cut | Speed | Feed | Coolant flow rate | $1$ | $2$ | $3$ | $\text{S/N value}$ |
|---------|--------------|-------|------|-------------------|-----|-----|-----|-----------------|
| 1       | 0.4          | 1400  | 0.05 | 0.02              | 0.69| 0.72| 0.67|                |
| 2       | 0.4          | 2000  | 0.15 | 0.05              | 2.22| 2.40| 2.20|                |
| 3       | 0.4          | 2600  | 0.25 | 0.1               | 2.74| 2.56| 2.87|                |
| 4       | 0.6          | 1400  | 0.15 | 0.1               | 2.03| 2.06| 2.02|                |
| 5       | 0.6          | 2000  | 0.25 | 0.02              | 1.90| 1.80| 2.14|                |
| 6       | 0.6          | 2600  | 0.05 | 0.05              | 0.71| 0.68| 0.76|                |
| 7       | 0.8          | 1400  | 0.25 | 0.05              | 1.75| 1.76| 1.75|                |
| 8       | 0.8          | 2000  | 0.05 | 0.1               | 0.68| 0.69| 0.74|                |
| 9       | 0.8          | 2600  | 0.15 | 0.02              | 0.84| 0.73| 0.88|                |

The average effects and S/N ratios for each level of cutting parameter are summarized and referred to in the average effects response table and S/N ratios response table roughness (Ra), as shown in Table 5 and 6.
Table 5. Average effect response the raw data

| Levels | Depth of cut (A) | Spindle speed (B) | Feed rate (C) | Coolant flow rate (D) |
|--------|-----------------|------------------|---------------|----------------------|
| 1      | 1.89            | 1.49             | 0.70          | 1.45                 |
| 2      | 1.56            | 1.62             | 1.70          | 1.57                 |
| 3      | 1.09            | 1.41             | 2.13          | 1.82                 |
| Max- Min | 0.80         | 0.22             | 1.42          | 0.66                 |
| Rank   | 2               | 4                | 1             | 3                    |

Table 6. Average effect response for S/N ratio

| Levels | Depth of cut (A) | Spindle Speed (B) | Feed rate (C) | Coolant flow rate (D) |
|--------|-----------------|------------------|---------------|----------------------|
| 1      | -5.46           | -2.62            | 3.05          | -0.31                |
| 2      | -3.04           | -3.28            | -3.87         | -3.04                |
| 3      | -0.02           | -1.37            | -7.86         | -3.93                |
| Max-Min | 5.44         | 1.91             | 10.91         | 3.62                 |
| Rank   | 2               | 4                | 1             | 3                    |

4. Pareto anova

It is a quick and easy method for analyzing result. This method enables the significance of factors and allows the optimal levels of factors to be obtained, as shown in Table 7.

Table 7. Pareto anova

| Factor                  | A  | B    | C    | D    | Total |
|-------------------------|----|------|------|------|-------|
| Sum at factor levels    | 1  | 5.67 | 4.47 | 2.10 | 3.45  |
|                         | 2  | 4.68 | 4.91 | 5.12 | 4.73  |
|                         | 3  | 3.27 | 4.25 | 6.41 | 5.45  |
| Sum of squares of differences | 8.72 | 0.67 | 29.46 | 6.14 | 44.88 |
| Contribution ratio (%)  | 19.42 | 1.49 | 65.37 | 13.68 | 100   |
| Overall optimum conditions for all factors | \( A_1 = 0.8 \) mm |
|                          | \( B_3 = 2600 \) rpm |
|                          | \( C_1 = 0.05 \) feed rate mm |
|                          | \( D_1 = 0.02 \) lit/sec |
Table 8. Pareto anova for raw data factor

| Pareto ANOVA for raw data Factor | A     | B     | C     | D     | Total |
|----------------------------------|-------|-------|-------|-------|-------|
| Sum at factor levels             |       |       |       |       |       |
| 1                                | -12.62| -7.86 | 9.07  | -0.79 |       |
| 2                                | -9.03 | -9.82 | -15.06| -9.09 | -21.69|
| 3                                | -0.04 | -4.01 | -19.32| -11.80|       |
| Sum of squares of differences     | 251.82| 51.66 | 1290.14| 197.43| 1791.05|
| Contribution ratio (%)           | 14.05 | 2.88  | 72.03 | 11.023| 100   |

Overall optimum conditions for all factors:
- A = 0.8 mm
- B = 2600 rpm
- C = 0.05 feed rate mm
- D = 0.02 lit/sec

4.1. Response graphs are drawn with parameters and levels

Figure 1. Average effect response chart for the raw data
Figure 2. Average effect response chart for S/N ratio
Figure 3. Pareto ANOVA for Raw Data

Figure 4. Pareto ANOVA for S/N Ratio
Table 9. ANOVA for raw data

| Square of variation | Sum of square | Degree of freedom | Mean of square | F_{cal} | F_{tal} |
|---------------------|---------------|------------------|----------------|---------|---------|
| Depth of cut        | 2.95          | 2                | 1.47           | 32.22   | 6.01    |
| Spindle speed       | 0.22          | 2                | 0.11           | 2.51    | 6.01    |
| Feed rate           | 9.74          | 2                | 4.87           | 108.20  | 6.01    |
| Coolant flow rate   | 1.56          | 2                | 0.78           | 17.30   | 6.01    |
| Error               | 0.81          | 18               | 0.04           |         |         |
| Total               | 15.28         | 26               |                |         |         |

In order to determine which cutting parameter significantly affect the quality characteristic for S/N Ratio. Table 9 shows the results of ANOVA analysis of S/N Ratio for surface roughness. From Table 10 it is apparent that the F values of factor A (depth of cut), and factor C (feed rate) were all greater than F_{0.01,2,18}(0.01,2,18) = 6.01. Figure 1 and Figure 2 represents average effect response chart for raw data and S/N ratio respectively. Figure 3 and Figure 4 represents Pareto ANOVA for the raw data and S/N ratio respectively.

Table 10. ANOVA for raw data

| Square of variation | Sum of square | Degree of freedom | Mean of square | F_{cal} | F_{tal} |
|---------------------|---------------|------------------|----------------|---------|---------|
| Depth of cut        | 83.63         | 2                | 41.81          | 13.02   | 6.01    |
| Spindle speed       | 17.40         | 2                | 8.7            | 2.71    | 6.01    |
| Feed rate           | 431.0         | 2                | 215.5          | 67.13   | 6.01    |
| Coolant flow rate   | 8.09          | 2                | 4.04           | 1.25    | 6.01    |
| Error               | 58.33         | 18               | 3.27           |         |         |
| Total               | 598.45        | 26               |                |         |         |

4.2. Predicting optimum performance
The optimal surface roughness and S/N ratio are predicted at the selected optimal setting of process parameter is shown in Table 11. The significant parameters with optimal levels are selected as:

Predicted optimal surface roughness
\[
\hat{y} = \bar{A}_1 + \bar{C}_3 + \bar{D}_1 - 2\bar{y} \\
= 1.09 + 1.70 + 1.45 - 2(1.48) \\
= 0.30 \mu m
\]

Predicted optimal S/N ratio
\[
\hat{y} = \bar{A}_1 + \bar{C}_3 - \bar{y} \\
= (-5.46) + (-7.86) - (-21.85) \\
= 8.23 dB
\]

4.3. Confirmation Experiment.

Conformation experiment was contacted at the optimum setting Ra values at optimum are
Table 11. The values obtained in the experiments are in the Predicted limits

| Trial 1 | Trial 2 | Trial 3 | mean | S/N Ratio |
|---------|---------|---------|------|-----------|
| 0.59    | 0.49    | 0.55    | 0.54 | 5.72      |

5. Conclusion

Table 12. The Optimal setting process parameter for optimal surface roughness

| S.NO  | Parameter         | Optimal levels |
|-------|-------------------|----------------|
| 1     | Depth of cut      | 0.8            |
| 2     | Spindle speed     | 2600           |
| 3     | Feed rate         | 0.05           |
| 4     | Coolant flow rate | 0.02           |

Table 13. The percent contribution of raw data

| 1     | Parameter          | Percent contribution on surface roughness |
|-------|--------------------|-------------------------------------------|
| 1     | Depth of cut       | 19.42                                     |
| 2     | Spindle speed      | 1.49                                      |
| 3     | Feed rate          | 65.37                                     |
| 4     | Coolant flow rate  | 13.68                                     |

The predicted optimal surface roughness = 0.01≤Ra≤0.59 (µm)
The calculation C.I for confirmation runs =±0.29.
The predicted optimal range (99% C.I) of the surface roughness for confirmation runs: Ra<0.59(µm).
The average value of surface roughness for confirmation runs at the optimal setting of turning process parameters was found to be 0.54µm. this result was within the predicted optimal surface roughness therefore, the optimum surface roughness was verified in turning operations is shown in Table 12 and 13.
Table 14. The percent contributions of S/N ratio parameters in affecting variation in surface roughness while machining aluminum turning operation.

| S.NO | Parameter          | Percent contribution on surface roughness |
|------|-------------------|------------------------------------------|
| 1    | Depth of cut      | 14.05                                    |
| 2    | Spindle speed     | 2.88                                     |
| 3    | Feed rate         | 72.03                                    |
| 4    | Coolant flow rate | 11.02                                    |

The predicted optimal surface roughness = 5.39 ≤Ra ≤11.37 dB

The calculation C.I for confirmation runs = ±2.84

The predicted optimal range (99% C.I) of the surface roughness for confirmation runs: Ra<11.37dB

The S/N Ratio value of surface roughness for confirmation runs at the optimal setting of turning process parameters was found to be 5.72dB. This result was within the predicted optimal S/N Ratio therefore, the optimum surface roughness was verified in turning operations are shown in Table 14.

6. References
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