Modeling and optimization of duplex turning parameters for Ni-718 using response surface modeling

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Abstract
Nickel alloy like (Ni-718) material is generally used in turbine blades. These alloys are having high strength as compared to their weight and high resistance to corrosion. The aim of present work is to model the responses and also to optimize duplex turning parameters. For this, response surface methodology (RSM) is jointly used with Taguchi methodology (TM) to achieve the experimental objective. The result of combined (TM-RSM) methodologies show improvement in responses as in primary cutting force = 13.6%, secondary cutting force = 9.19% and on average surface roughness = 8.69% positively compared to only TM methodology.

1. Introduction
Nickel alloy like Ni-718 is high strength mechanical alloy and it is very valuable material, as it has low density, high strength, high operating temperature and high corrosion resistance. But the high chemical affinity and low conductivity is main reason for its poor machinability as it causes high cutting forces, high tool wear and damages of sub-surfaces can take place during metal cutting [1, 2].

The characteristic of machined surface like surface quality and sub-surface damages have a significant effect on the properties like fatigue life, corrosion resistance and other tribological properties as it affects the machining performance and life of the component. Therefore a high degree of surface quality is required for better performance of the finished component. The machining forces are also important as it controls the residual stresses, stress concentration and temperature of cutting zone which directly affects the surface quality. Therefore, it is necessary to select the machining parameters which give moderate cutting forces and better surface quality [3, 4].

Thus, for selecting better parameter combination for getting better surface quality with moderate cutting forces a different method of turning i.e. duplex turning is proposed. The mechanism of duplex turning is shown in figure 1. Duplex turning shows some advantages over the normal turning like it eliminates secondary finishing operation as rough and finish operation is performed in one pass only with less cutting forces. Duplex turning also provides dynamic stability to the cutting process [5, 6].

Duplex turning is a newly developed process for machining turned surface and very little research work is published. Budak and Ozturk [7] observed that duplex turning made the process more stable as compared to normal turning. Kalidasan et al [8] experimentally observed the variation of distance between two (parallel) tools in turning. They observed high machining forces when offset distance between the tools was low. They also observed better dimensional accuracy in workpiece caused by machining forces. Kalidasan et al [5] analysed that due to presence of cutting force, workpiece at tail stoke side deflects more as compared to chuck side. They also observed that auxiliary tool exhibits more heat than primary tool. Kalidasan et al [9] observed that use of double tool in turning to produce good quality surfaces as compared to a single tool. A similar type of observation was also made by Yadav [10] in which they analysed that that use of secondary tool in turning enhanced surface quality.
Experimental observation of double tool turning on Ti-alloy was made by Kumar et al.\cite{6} they observed the improvement in cutting forces and surface quality compared to single tool turning. Yadav\cite{11} developed second-order response model for Ti-alloy and found the improvement in cutting forces and surface quality.

Statistical techniques like Taguchi method (TM) and response surface methodology (RSM) are found helpful for optimization and modeling of process parameters. Nalbant et al.\cite{12} utilized Taguchi $L_9$ matrix and ANOVA for minimizing surface roughness. They observed improvement in surface quality as 33.5\% at optimal level. Bhattacharya et al.\cite{13} utilized Taguchi $L_{16}$ matrix to minimize the multi-responses like surface roughness and power consumption. They observed conflicting results for power consumption with surface quality at 235 m min$^{-1}$ of speed and 0.125 mm/rev of feed rate. Akincioglu et al.\cite{14} utilized $L_9$ matrix for optimizing turning parameters. They observed better surface quality at cutting speed at 90 m min$^{-1}$. Ramana and Aditya\cite{15} utilized $L_{27}$ matrix to minimize surface roughness in turning for Ti-alloy. They observed improvement in surface quality at an optimal level of TM Upadhyay et al.\cite{16} utilized TM technique in machining of Ni-601 alloy. They observed improvement in responses at optimal level of TM. Mia et al.\cite{17} utilized TM technique to get better parameter combination in turning. They observed improvement in multi-responses like cutting force and surface quality at optimal condition. Yildirim et al.\cite{18} employed TM technique for optimizing turning parameters and observed improvement in tool life, surface quality and temperature at optimal condition.

Muhammad et al.\cite{19} utilized quality loss function for multi-responses of resistance spot welding. They optimized result by using multiple S/N ratios (MSNR) and observed improvement in all responses using proposed technique. They further developed linear response surface models and found that it was well fitted to response data. Muhammad et al.\cite{20} optimized multi-response parameter of spot welding using MSNR. Their result shows effectiveness of TM approach. They also developed a linear surface model and found that a hybrid approach was a very effective method to predict weld zone. Muhammad et al.\cite{21} utilized Taguchi $L_9$ matrix and quality loss function to optimize multi-responses parameters for resistance spot welding. They convert multi-responses in total normalized quality loss and observed the enhancement in all responses using proposed technique. Muhammad and Manurung\cite{22} developed RSM models for weld nugget radius and HAZ size. They observed good agreement in predicted value with optimal level.

Noordin et al.\cite{23} utilized RSM technique for getting better parameter combination for better surface quality and moderate cutting force. They observed a significant effect of feed rate on responses. Boucha et al.\cite{24} utilized second-order response models and desirability function approach and observed improvement in responses (surface roughness and cutting forces) at optimal level. Bouzid et al.\cite{25} developed response models for turning parameters. They also utilized ANOVA, to find the significance of proposed model and contribution of each parameter. They observed that cutting depth had maximum effect on cutting force while feed rate had maximum effect on surface roughness.

Dubey and Yadava\cite{26} utilized Taguchi and response surface model (TM-RSM) in laser cutting of thin sheets. They utilized quality loss function and MSNR to identify the optimal value of TM. They further utilized these optimal values in RSM to developed second-order response models. They also observed that a combination of two approaches was slightly better as compared to individual effort. Singh et al.\cite{27} utilized Taguchi $L_9$ matrix, quality loss value and MSNR to identify optimal level of parameter in electro discharge grinding. They developed response model by utilizing optimal level of TM as central value in RSM. They observed that proposed technique gives improvement in responses as compared to TM optimal value.
[28] utilized Taguchi L9 matrix to obtain quality loss value and optimal parameter level for duplex turning. They further developed RSM model for surface roughness. They revealed that a combination of two techniques gives better parameter combination as compared to optimal level of TM technique.

In present work, two techniques (TM-RSM) are used together for modeling and optimization of duplex turning parameters for Ni-alloy. The TM technique is used to find the optimal level of duplex turning parameters like cutting speed, feed-rate, primary-cutting depth (DC) and secondary-DC. These optimal levels are used in RSM for modeling the responses like primary cutting force, secondary cutting force and average surface roughness. Further, ANOVA is performed and significance of RSM model is checked. D-optimality approach is used for getting optimal parameter level and corresponding responses. Finally, these response values are compared with optimal value of TM.

2. Experimental planning

2.1. Taguchi methodology

Design matrix for Taguchi analysis is decided by using degree of freedom (DoF), it depends on process parameters and their levels [26, 29]. DoF can be obtained by equation (1).

\[
\text{DoF} = (\text{Factor level} - 1) \times (\text{Factor level} - 1) + 1
\]  

(1)

In Taguchi methodology, S/N ratio (η) is utilized for analyzing the responses and it depends on experimental objective and nature of responses. In our analysis responses are minimizing in nature, therefore, Smaller the Better (SB) type method is used for calculating S/N ratio as given in equation (2).

\[
\eta = -10 \log (\text{MSD})
\]  

(2)

Here, MSD = quality loss value and for SB type it is calculated by equation (3).

\[
\text{MSD} = -10 \log \left( \frac{1}{n} \sum_{i=1}^{n} y_i^2 \right)
\]  

(3)

Here \(y_i\) = mean value, \(n\) = trials in numbers.

The ANOVA is performing on S/N ratios to get parameter effects in terms of percentage contribution and F-ratio. Here, F-ratio shows the variation of machining parameters with response. Finally, the means of S/N ratio is obtained and optimal levels are identified.

For more than one objective function multiple S/N ratios (MSNR) are calculated instead of single S/N ratio. The MSNR depends on total normalized quality loss (TNQL), calculated by normalizing the quality loss function for individual responses [20, 26]. The MSNR, normalized quality loss and TNQL is calculated by equations (4)–(6) positively.

\[
\text{MSNR} = -10 \log \sum_{i=1}^{k} Y_j
\]  

(4)

\[
Y_j = \left[ \sum_{i=1}^{k} w_i y_{ij} \right]
\]  

(5)

\[
y_{ij} = \frac{Q_{ij}}{Q_{max}}
\]  

(6)

Here \(Y_j\) = TNQL value for \(j^{th}\) trial, \(y_{ij}\) = normalized quality loss for \(j^{th}\) trial, \(w_i\) = weight assigned to each response, \(Q_{ij}\) = MSD or quality loss, \(Q_{max}\) = maximum quality loss for \(j^{th}\) response and \(k\) = number of responses.

2.2. Response surface method

A central composite rotatable design (CCRD) matrix is utilized for RSM models. In CCRD if \(P\) = control factors, it requires \(2n\) factorial design experiments and \(2P + 1\) are additional factors [30]. Generally, RSM model is given by equation (7).

\[
Y = \beta_0 + \sum_{i=1}^{n} \beta_i x_i + \sum_{i=1}^{n} \beta_{ii} x_i^2 + \sum_{i=1}^{n} \sum_{j=i+1}^{n} \beta_{ij} x_i x_j
\]  

(7)

Here, \(Y\) = centerline values for responses, \(\beta_0\) = constant term, \(\beta_i\), \(\beta_{ii}\) and \(\beta_{ij}\) = coefficient of regression, \(x_i\), \(x_j\) = inputs.
3. Experimental procedure

All the experiments are performed on Center lathe machine in-build with auxiliary tool post. Both the tool post are mounted on same carriage, therefore the feed per revolution of both tool is same whereas cutting depth (DC) can be different. The duplex turning process is shown in figure 2. Two single-point Cemented Carbide tools are utilized turning Ni-alloy and its properties are given in table 1.

The TR-200 roughness tester with following specification, measuring system as metric μm, cut-of-length as 0.8 mm, Display resolution as 0.001 μm /0.04 μ inch and LCD display having 128 × 64 dot-matrixes has been utilized for measuring surface roughness. The strain gauge dynamometer with following specification, model number is MLB-LDI-500, measuring capacity of 5kN, acquisition frequency of 50 Hz with accuracy of 1% traceable to national a physical laboratory, has been utilized for observing cutting forces. The notation for turning parameters is taken as $V$ = cutting speed in m/min, $f$ = feed rate in mm/rev, $D_p$ = primary-CD in mm and $D_s$ = secondary-CD in mm. Notation for multi responses is taken as $F_p$ = primary cutting force in N, $F_s$ = auxiliary cutting force in N and $Ra$ = average surface roughness in μm.

The range of turning parameters and their levels are decided by preliminary test and listed in table 2. In present analysis, four parameters and three levels are used, therefore, from equation (1),

$$DF = [(3-1) \times 4] + 1 = 9.$$  Hence, Taguchi L₉ matrix is selected for experimentation and listed in table 3. For RSM modeling total runs are $2^P$ (factorial run) + $2^P$ (axial run) + 7 runs at centre. For four parameters ($P = 4$), the total experimental runs are given as $2^4 + 2^4 + 7 = 31$. The experimental data for modeling the responses are presented in table 5.

![Figure 2. Duplex turning.](image)

| Table 1. Nickel alloy composition in percentage. |
|-----------------------------------------------|
| Nickel | Chromium | Niobium | Molybdenum | Iron |
|--------|----------|---------|------------|------|
| 54.48  | 17.50    | 4.90    | 4.85       | Balance |

| Table 2. Level of turning parameter for TM experiments. |
|--------------------------------------------------------|
| Notation | Turning parameters | Levels |
|----------|--------------------|--------|
| $V$      | Cutting speed      | 60 90 120 |
| $f$      | Feed rate          | .08 .10 .12 |
| $D_p$    | Primary-CD         | .20 .50 .80 |
| $D_s$    | Secondary-CD       | .20 .40 .60 |
Table 3. Experimental data for L9 matrix.

| Exp. no. | V   | f   | Dp | Ds | $R_a$ | $R_a$ (Avg.) | $F_p$ | $F_p$ (Avg.) | $F_s$ | $F_s$ (Avg.) |
|---------|-----|-----|----|----|-------|-------------|-------|-------------|-------|-------------|
| 1       | 1   | 1   | 1  | 1  | 2.95  | 2.91        | 2.93  | 158.11      | 157.21| 157.66      |
| 2       | 1   | 2   | 2  | 2  | 3.12  | 3.29        | 3.20  | 286.13      | 285.11| 285.62      |
| 3       | 1   | 3   | 3  | 3  | 3.89  | 3.81        | 3.85  | 367.99      | 367.14| 367.56      |
| 4       | 2   | 1   | 2  | 2  | 3.02  | 2.96        | 2.99  | 146.31      | 147.21| 146.76      |
| 5       | 2   | 2   | 3  | 1  | 2.82  | 2.88        | 2.85  | 199.10      | 201.12| 200.11      |
| 6       | 2   | 3   | 1  | 2  | 3.69  | 3.61        | 3.65  | 323.77      | 325.11| 324.44      |
| 7       | 3   | 1   | 3  | 3  | 2.99  | 3.06        | 3.02  | 210.49      | 211.23| 210.86      |
| 8       | 3   | 2   | 1  | 3  | 2.88  | 3.06        | 3.02  | 171.21      | 171.19| 171.19      |
| 9       | 3   | 3   | 2  | 1  | 3.49  | 3.41        | 3.45  | 308.25      | 309.11| 308.68      |

Table 4. Factors and their levels for RSM modeling.

| Turning parameters | Coded values |
|--------------------|--------------|
| V                  | −2 −1 0 1 2  |
| f                  | 0.06 0.08 0.10 0.12 0.14 |
| Dp                 | 0.10 0.30 0.50 0.70 0.90 |
| Ds                 | 0.10 0.15 0.20 0.25 0.30 |

Table 5. Observations for RSM modeling.

| Exp. no. | V   | f   | Dp | Ds | $F_p$ (N) | $F_s$ (N) | $R_a$ (μm) |
|----------|-----|-----|----|----|-----------|-----------|------------|
| 1        | 0   | 0   | 0  | 0  | 171.21    | 171.19    | 3.01       |
| 2        | 0   | 0   | 0  | 0  | 171.01    | 169.12    | 2.99       |
| 3        | 0   | 0   | 0  | 0  | 176.11    | 171.12    | 3.05       |
| 4        | 0   | 0   | 0  | 0  | 171.21    | 168.14    | 2.96       |
| 5        | 0   | 0   | 0  | 0  | 168.07    | 167.14    | 2.94       |
| 6        | 0   | 0   | 0  | 0  | 178.14    | 167.14    | 2.91       |
| 7        | 0   | 0   | 0  | 0  | 171.11    | 168.21    | 2.94       |
| 8        | −1  | −1  | −1 | −1 | 167.24    | 166.11    | 2.86       |
| 9        | 1   | −1  | −1 | −1 | 157.11    | 156.11    | 2.84       |
| 10       | −1  | 1   | −1 | −1 | 221.15    | 218.21    | 3.13       |
| 11       | 1   | 1   | −1 | −1 | 191.14    | 187.17    | 3.11       |
| 12       | −1  | −1  | 1  | −1 | 161.07    | 162.21    | 2.85       |
| 13       | 1   | −1  | 1  | −1 | 158.26    | 146.13    | 2.81       |
| 14       | −1  | 1   | 1  | 1  | 321.08    | 298.18    | 3.23       |
| 15       | 1   | 1   | 1  | −1 | 353.11    | 313.11    | 3.56       |
| 16       | −1  | −1  | −1 | 1  | 169.15    | 178.14    | 3.07       |
| 17       | 1   | −1  | −1 | 1  | 158.04    | 168.17    | 2.81       |
| 18       | −1  | 1   | −1 | 1  | 326.07    | 311.11    | 3.28       |
| 19       | 1   | 1   | −1 | 1  | 326.07    | 311.11    | 3.28       |
| 20       | −1  | 1   | 1  | −1 | 363.21    | 323.11    | 3.66       |
| 21       | 1   | 1   | 1  | 1  | 357.06    | 343.11    | 3.41       |
| 22       | −1  | −1  | 1  | 1  | 162.22    | 158.12    | 2.92       |
| 23       | 1   | −1  | 1  | 1  | 161.05    | 156.21    | 2.91       |
| 24       | 0   | 0   | 0  | 2  | 174.21    | 187.14    | 3.08       |
| 25       | 0   | 0   | 2  | 0  | 311.12    | 171.02    | 3.11       |
| 26       | 0   | 2   | 0  | 0  | 387.22    | 376.11    | 3.61       |
| 27       | 2   | 0   | 0  | 0  | 162.31    | 158.14    | 2.76       |
| 28       | 0   | 0   | 0  | −2 | 176.14    | 161.08    | 2.99       |
| 29       | 0   | 0   | −2 | 0  | 171.17    | 168.51    | 2.89       |
| 30       | 0   | −2  | 0  | 0  | 166.21    | 161.41    | 2.78       |
| 31       | −2  | 0   | 0  | 0  | 192.11    | 182.12    | 2.97       |
4. Result and discussion

4.1. Multi-objective optimization by TM

From Taguchi L9 matrix data (table 3) quality loss and normalized quality loss is calculated using equations (3) and (6) and listed in table 6. Equation (5) and (4) are utilizing for calculating TNQL and MSNR, listed in table 6. TNQL is calculated by assigning weight for each response ($w_1 = 0.2$ for $F_p$, $w_2 = 0.2$ for $F_s$ and $w_3 = 0.6$ for $R_a$) positively because the primary objective is to maintain better surface quality, therefore, higher weight is assigned to $R_a$. The mean MSNR is calculated in table 7 and graph for MSNR with parameter level given in figure 3. It is observed that $V$ as 120 m min$^{-1}$, $f$ as 0.10 mm/rev, $D_p$ = 0.50 mm and $D_s$ as 0.20 mm is an optimal condition of TM technique. Hence, the condition $V_3-f_2-D_p_2-D_s_1$ is the optimal condition.

The ANOVA technique has utilizes on MSNR values (table 6) it measures relative effect for each factor in terms of a sum square, mean square, F-ratio and percentage contribution (PC). The ANOVA analysis and their results are listed in table 8 and figure 4. The PC of four parameter on the responses are as $f = 74.94\%$, $D_s = 11.37\%$, $V = 7.58\%$, $D_p = 0.06\%$. It is observed (table 8) that the maximum contribution of feed rate on responses compared to other parameters.

Confirmation test has also performed for verifying optimum level of TM analysis. The experimental results of confirmation experiment and predicted values at initial set of parameters are given in table 9. The improvement in responses are obtained as $F_p = 5.66\%$, $F_s = 12.04\%$ and $R_a = 6.44\%$.

| Table 6. Quality loss, TNQL and MSNR. |
|---------------------------------------|
| Exp. no. | Quality loss (dB) | Normalized quality loss (dB) | TNQL | MSNR |
|          | $F_p$ | $F_s$ | $R_a$ | $F_p$ | $F_s$ | $R_a$ |
| 1        | 24856.67 | 24287.66 | 8.585 | 0.18 | 0.22 | 0.579 | 0.4288 | 3.677 |
| 2        | 81578.78 | 72003.67 | 10.272 | 0.60 | 0.66 | 0.693 | 0.4609 | 3.372 |
| 3        | 135100.35 | 72800.13 | 14.82 | 1.00 | 0.67 | 1.00 | 0.9339 | 0.297 |
| 4        | 21538.49 | 37152.56 | 8.94 | 0.16 | 0.34 | 0.603 | 0.4661 | 3.350 |
| 5        | 40044.01 | 28250.88 | 8.12 | 0.30 | 0.26 | 0.548 | 0.4400 | 3.560 |
| 6        | 105261.31 | 108672.41 | 13.32 | 0.78 | 1.00 | 0.899 | 0.8962 | 0.4759 |
| 7        | 44461.31 | 38032.80 | 9.15 | 0.33 | 0.35 | 0.617 | 0.5062 | 2.95 |
| 8        | 59931.93 | 70572.57 | 8.12 | 0.44 | 0.65 | 0.548 | 0.3473 | 4.59 |
| 9        | 95288.34 | 81250.65 | 11.90 | 0.70 | 0.75 | 0.801 | 0.4823 | 3.17 |

| Table 7. Parameter levels of MSNR. |
|----------------------------------|
| Mean (MSNR) | $V$ | $f$ | $D_p$ | $D_s$ |
| Level 1 | 2.445 | 3.33 | 2.91 | 3.47 |
| Level 2 | 2.46 | 3.84 | 3.29 | 2.27 |
| Level 3 | 3.57 | 1.31 | 2.27 | 2.73 |
4.2. Modeling using RSM

The response models are developed by using the CCRD experimental data (table 5) by using MINITAB-17 version software. The RSM models for the responses in the coded unit are given in equations (6)–(8).

\[
F_p = 173.69 - 5.08V + 66.58 \times f + 26.41D_p + 7.15 \times D_s + 3.62 \times V^2 \\
+ 28.50 \times f^2 + 19.60D_p^2 + 3.11D_s^2 - 0.74V \times f + 6.63V \times D_p \\
+ 2.74V \times D_s + 23.24f \times D_p + 10.12f \times D_s - 15.25 D_p \times D_s 
\]

(8)

\[R^2 = 93.98\% \text{ and } R^2 (\text{adj}) = 88.71\% \]

\[
F_s = 168.87 - 4.04V + 59.51f + 9.34D_p + 12.05D_s \\
+ 5.01V^2 + 29.66f^2 + 4.91D_p^2 + 6.00D_s^2 + 1.68V \times f \\
+ 5.18V \times D_p + 5.32V \times D_s + 19.42f \times D_p \\
+ 11f \times D_s - 13.43D_p \times D_s 
\]

(9)
\[ R^2 = 93.31\% \text{ and } R^2\text{(adj)} = 87.46\% \]

\[ R_a = 2.97 - 0.03 \times V + 0.22 \times f + 0.06 \times D_p + 0.01 \times V^2 \\
+ 0.07 \times f^2 + 0.02 \times D_p^2 + 0.029D_s^2 - 0.02V \times f \\
+ 0.03 \times V \times D_p - 0.04V \times D_s - 0.04 \times f \times D_p \\
- 0.04 \times f \times D_s - 0.006 D_p \times D_s \]  

\( 10 \)  

\[ R^2 = 91.91\% \text{ and } R^2\text{(adj)} = 84.83\% \]

The ANOVA, F-ratio and P-test have performed on developed models to check statistical significance and listed in table 10. From ANOVA (table 10), p-value of linear, square and regression models are zero for \( F_p \), \( F_s \) and \( R_a \). F-value of a lack-of-fit for responses is \( F_p = 6.845 \), \( F_s = 2.02 \) and \( R_a = 5.47 \) positively.

The capability of RSM model is also checked and verified by performing separate experiments and compared with model values. The experimental value and predicted values of responses are given in tables 11 and 12 and also shown in figures 5–7 positively. The predicted values follow the same trend as actual values with average absolute percentage error for \( R_a = 3.06\% \), \( F_p = 3.01\% \) and \( F_s = 3.42\% \) positively.

### 4.3. Optimization using hybrid TM-RSM

In this section optimal condition of duplex turning is obtained using TM-RSM technique. The RSM models of three responses have been optimized by desirability function approach by keeping the minimum value of three responses and turning parameter in range. The weights are assigned for responses are as \( w_1 = 0.2 \) for \( F_p \), \( w_2 = 0.2 \) for \( F_s \) and \( w_3 = 0.6 \) for \( R_a \). The desirability function graph is shown in figure 8. Here, \( D \) is composite desirability, \( d \) is individual desirability. From D-optimality result, minimum responses are observed as \( F_p = 128.11 \) N, \( F_s = 124.70 \) N, and \( R_a = 2.52 \mu m \) at cutting velocity = 160 mm min \(^{-1} \), \( FR = 0.08 \) mm/rev, \( D_p = 0.15 \) mm and \( D_s = 0.10 \) mm positively with high composite and individual desirability value of 1 (one).
The responses obtained from desirability graph are compared with TM optimal values. The percentage improvement in $F_p$, $F_s$ and $R_a$ is listed in table 13. The result shows that the responses are improved as $F_p = 13.6\%$, $F_s = 9.19\%$ and $R_a = 8.69\%$ as with hybrid approach as compared to TM optimal values.

**Figure 5.** Predicted and experimental for $R_a$.

**Figure 6.** Predicted and experimental for $F_p$.

**Figure 7.** Predicted and experimental for $F_s$. 

The responses obtained from desirability graph are compared with TM optimal values. The percentage improvement in $F_p$, $F_s$ and $R_a$ is listed in table 13. The result shows that the responses are improved as $F_p = 13.6\%$, $F_s = 9.19\%$ and $R_a = 8.69\%$ as with hybrid approach as compared to TM optimal values.
5. Conclusions

The optimal values for duplex turning parameters are selected from D-optimality test using hybrid TM-RSM technique. The Taguchi method predicts the optimal values by utilizing Taguchi quality loss function. This optimal value is taken as central-value in RSM and models for \( F_p \), \( F_s \) and \( R_a \) are developed. The statistical techniques (ANOVA) are performed, percentage contribution and significance each parameter on responses are observed. From D-optimality test, optimal values and corresponding responses are predicted. Therefore it may conclude that RSM combined with TM technique is an efficient way for modeling and optimization of duplex turning parameters.

Duplex turning also able to show lower tool wears, better tool life, better process efficiency, and lower vibration with lower wear and tear in machine tools as compared to normal turning. Even though, such process suffers because of high setting time.

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