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# Selection of Optimal Parameters Setting Through Taguchi -Fuzzy- FIS Simulation during Dry Turning of Inconel 718

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***Abstract:** The objective of the present study is to find out the optimal process parameter setting during dry turning of Inconel 718 work material. Dry turning was performed by considering the experimental steps according to Taguchi methodology. Speed, feed and depth of cut were considered as process parameters and the material removal rate (MRR) and surface roughness ($R_a$) were considered as output responses. ANOVA analysis considering MRR maximization indicated that all input process parameters that is speed (36%), feed (25%) and DOC (35%) have significant contribution towards maximization of MRR. But ANOVA analysis considering surface roughness minimization indicated that feed is the only influence contributing (50%) parameter for minimization of surface roughness. S/N ratios obtained from experimental observations were normalized and simulation through FIS (fuzzy inference system) using MATLAB software was carried out . The optimality condition was obtained at high speed (110m/min), high feed (0.16mm/rev) and medium depth of cut (1mm) .*

***Keywords:** Inconel718, ANOVA, Taguchi, FIS*

## 1. INTRODUCTION

Inconel 718 is a nickel based alloy having higher corrosion resistance ability and higher strength retention property at higher temperature. Inconel 718 is used in gas turbine and aviation industries. Out of total production cost during manufacturing of items, machining always has accounted for a higher percentage of total production cost. Proper emphasis should be provided to select proper input parameter settings through optimization. The Present analysis is based on Taguchi methodology decoupled with simulation through rule based fuzzy inference system (FIS). Selection of proper input process parameter can be done through this method to restore economic and production rate. The Present study is done by considering two different output responses, i.e. MRR and surface roughness for attainment of optimal parameters setting.

L B Abhang et al [1] worked on optimization of machining parameters in steel turning operation by Taguchi method. EN 31 steel was chosen as work material and tungsten carbide insert was chosen as tool material. Taguchi parameter design is explained systematically. An optimal combination of process parameters based on S/N ratio was obtained. ANOVA analysis was carried out to know the significance of each parameter. They also found out the effect of lubricant temperature on surface finish during turning. They found that lower lubricant temperature improves surface finish during turning..

Joao Eduardo Ribeiro et al [2] applied Taguchi methodology to find out the optimal machining condition to improve surface quality during milling of hardened steel (steel 1.2738). They explained the influence of machining parameters on surface quality. ANOVA was performed to obtain the influence of each parameter. They considered cutting speed, feed rate, radial depth and axial depth as input parameters. It was noted that the minimum roughness were 1.05 microns. They found that interaction between the radial and axial depth of cut was the most relevant parameter.

Surendra Kumar Saini et al [3] used $L_{27}$ Taguchi orthogonal arrays during turning of Aluminium alloy 8011 in CNC lathe with carbide insert. They considered cutting speed, feed and depth of cut as process parameters and material removal rate and surface roughness as two output responses. .Optimum set of turning process parameter was ascertained by Taguchi – Fuzzy application. They observed that feed is the most significant process parameter followed by the depth of cut and cutting speed on the selected response parameters.

## 2. EXPERIMENTAL PROCEDURE

Dry turning of Inconel 718 was made on a lathe. The lathe is gear driven having a speed range of 45 rpm to 1000 rpm and feed range of 0.06mm/rev to 1.72mm/rev. The Inconel 718 work material was a round bar of 37mm diameter and 300mm length. Tungaloy made SNMG120404TM T9125 was used for machining of Inconel718. Tool holder used for the purpose was

Tungaloy made ASBNR 25 × 25 M12-A. Selected input parameters at 3 different levels are shown in table1.

**TABLE 1: Input parameters for Inconel 718**

| Factors | Level 1 | Level 2 | Level 3 |
|---|---|---|---|
| Coding | 1 | 2 | 3 |
| Speed,m/min | 40 | 70 | 110 |
| Feed,mm/rev. | 0.06 | 0.10 | 0.16 |
| D.O.C,mm | 0.5 | 1 | 1.5 |

Based on the above given input process parameters, Taguchi design of experiments was done which provided 9 different combinations. Subsequently, surface roughness values were measured by 3D optical surface roughness profilometer for 9 different experimental conditions. Table 2 shows the arrangement of input process parameters according to the Taguchi orthogonal L9 array.

**TABLE 2: L9 Orthogonal array**

| Sl.No. | Codes | | | Velocity m/min (v) | Feed mm/rev (f) | d.o.c mm (D.O.C) |
|---|---|---|---|---|---|---|
| | v | f | d | | | |
| 1 | 1 | 1 | 1 | 40 | 0.06 | 0.5 |
| 2 | 1 | 2 | 2 | 40 | 0.10 | 1.0 |
| 3 | 1 | 3 | 3 | 40 | 0.16 | 1.5 |
| 4 | 2 | 1 | 2 | 70 | 0.06 | 1.0 |
| 5 | 2 | 2 | 3 | 70 | 0.10 | 1.5 |
| 6 | 2 | 3 | 1 | 70 | 0.16 | 0.5 |
| 7 | 3 | 1 | 3 | 110 | 0.06 | 1.5 |
| 8 | 3 | 2 | 1 | 110 | 0.10 | 0.5 |
| 9 | 3 | 3 | 2 | 110 | 0.16 | 1 |

## 3. THEORY

### *3.1. The Material removal rate*

The material removal rate can be determined by the equation (1)

$$\text{Material removal rate} = \frac{\pi\,[(D^2-d^2)L]/4}{L/(fN)} \quad (1)$$

Where, D =Initial diameter
d= Final diameter
L=Distance moved by the tool during each experiment.
N=R.P.M
F=feed

### *3.2. Performance evaluation of Tguchi methodology*

For material removal rate, the higher the better criterion is followed and S/N ratios are obtained by equation (2)

$$\textbf{(S/N) ratio} = -10 \log [1/n\{\textstyle\sum (1/y^2)\}] \quad (2)$$

where y is average of response parameter values.

For surface roughness ($R_a$), lower the better criterion is chosen and (S/N) values are found by equation (3)

$$\text{(S/N) ratio} = -10 \log[1/n\{(\textstyle\sum(y^2)\}] \quad (3)$$

Where y is average of response parameter values

## 4. RESULTS AND DISCUSSION

Experimental results following Taguchi L9 orthogonal design are shown in table3.

**TABLE 3: Data on MRR and $R_a$**

| Sl No | MRR ($mm^3/s$) | Surface roughness, $R_a$, ( Micron) |
|---|---|---|
| 1 | 22.934 | 0.777 |
| 2 | 75.398 | 1.737 |
| 3 | 178.442 | 2.531 |
| 4 | 95.254 | 1.339 |
| 5 | 95.530 | 2.128 |
| 6 | 96.321 | 1.333 |
| 7 | 219.911 | 1.423 |
| 8 | 95.557 | 3.837 |
| 9 | 301.593 | 1.319 |

Average values of MRR and $R_a$ at 9 different experimental conditions are noted (table3) and subsequently (S/N) ratios were calculated for both MRR and surface roughness (Table4 ).

**TABLE 4: Calculated S/N ratios**

| Sl. No | S/N ratio for mrr | S/N ratio for surface roughness |
|---|---|---|
| 1 | 27.2081 | 2.1916 |
| 2 | 37.5474 | -4.7960 |
| 3 | 45.0298 | -8.0658 |
| 4 | 39.5773 | -2.5356 |

| Sl. No | S/N ratio for mrr | S/N ratio for surface roughness |
|---|---|---|
| 5 | 39.6028 | -6.559 |
| 6 | 39.6743 | -2.4966 |
| 7 | 46.8445 | -3.0641 |
| 8 | 39.6055 | -11.6798 |
| 9 | 49.5883 | -2.4039 |

ANOVA analysis was done by Matlab programming considering S/N ratios for MRR and results are shown in table5 and fig1 .

**TABLE 5: ANOVA of S/N values (MRR)**

| Source | SS | DOF | Variance | F ratio | P cont. |
|---|---|---|---|---|---|
| Speed | 118. 5383 | 2 | 59. 2642 | 8. 9005 | 35. 7125 |
| Feed | 82. 6939 | 2 | 41. 3470 | 6. 2096 | 24. 9156 |
| D.O.C | 117. 3568 | 2 | 58. 6784 | 8. 8125 | 35. 3596 |
| Total | 331. 8962 | 8 | | | |
| Error | 13. 3171 | 2 | 6. 6585 | | 4. 0124 |

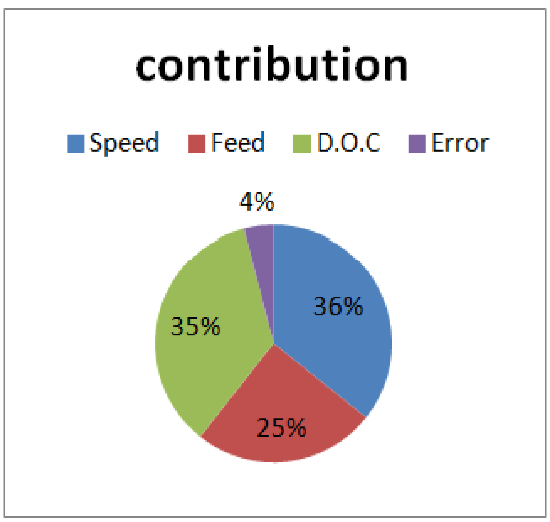



**Fig. 1. Percentage contribution of input parameters for mrr**

From table 5 and Fig. 1, it is seen that with reference to MRR consideration, percentage contribution of speed (36%) and DOC (35%) are almost similarly higher and the percentage contribution of feed (25%) is to some extent is smaller. This shows that each input parameter is influential and significant.

ANOVA analysis was also done by Matlab programming considering S/N ratios for $R_a$ and results are shown in table 6 and fig 2

**TABLE 6: ANOVA of S/N values (Surface roughness, $R_a$)**

| Source | SS | DOF | Variance | F ratio | P Cont. |
|---|---|---|---|---|---|
| Speed | 8.1870 | 2 | 4.0915 | 0.1863 | 6.4179 |
| Feed | 64.2157 | 2 | 32.1078 | 1.4609 | 50.3397 |
| D.O.C | 11.205 | 2 | 5.6029 | 0.2549 | 8.7844 |
| Total | 127.5648 | 8 | | | |
| Error | 43.9562 | | 21.9781 | | 34.4579 |

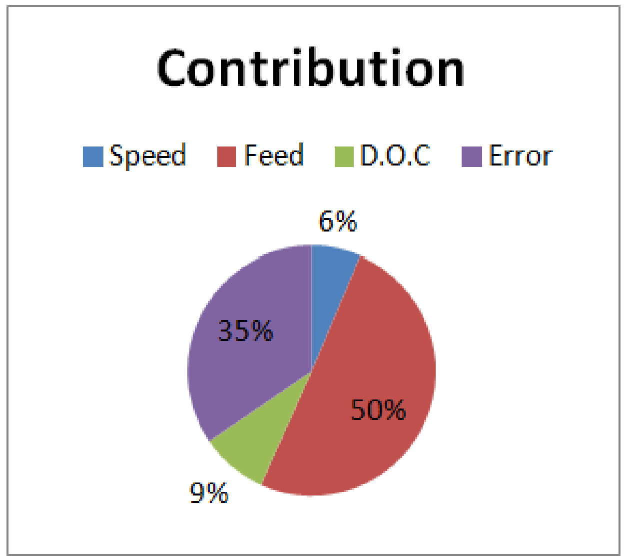



**Fig. 2. Percentage contributions of input parameters for $R_a$**

From table 6 and Fig.2, it is seen that with reference to surface roughness consideration during machining of super alloy Inconel 718, highest percentage contribution is attained with feed (50%) in comparison to DOC (9%) and speed (6%). DOC and speed has very low influence at the proposed consideration of machining.

The machining behavior of super alloy inconel718 is not at all favorable because of the formation of adiabatic shear instability condition at the primary deformation zone(PDZ) during machining. Such transition of this material at the PDZ is usually encountered because of very poor thermal conductivity of this material. Developed heat at the PDZ gets accumulated at the cutting zone and can not get transferred to the surrounding during machining because of the poor thermal conductivity of this material. This causes thermal instability and the mode of chip formation takes place in an unfavorable manner affecting dimensional stability [4,5,6]. Surface finishing during machining takes place in an uncontrolled mode and thus the surface finish values at various experimental conditions become statistically improper. In the present study also ANOVA table6 for surface roughness consideration does not show the proper influence of DOC and speed. However , this analysis shows significant influence (50%) of feed only.

In order to find out the optimal setting of input parameters, higher MRR is chosen for higher production rates and for proper control over the economy in the production process. Thus Taguchi's higher the better criterion is applicable for this response parameter. Since, surface roughness are selected as a second response parameter for optimal input parameter selection, therefore, Taguchi's lower the better criterion is preferred to emphasize better surface quality of the manufacturing item. Multi Performance characteristic index (MPCI) has been considered as an output response parameter. Higher MPCI denotes better production rate with improved surface quality of the manufactured item. For simulation work, MRR and $R_a$ are considered as input parameters and MPCI is considered as an output parameter.

Membership functions of MRR and $R_a$ are shown in fig 4 and fig 5. Membership function of MPCI is shown in fig 6.

Considering these criteria, a set of rules was framed based on experience to perform the simulation work . Rules are framed emphasizing mainly on higher production rate with improvement in surface quality. Following is the implemented set of rules introduced during simulation.

1. If (MRR is low) and (Ra is low) then (MPCI is very small)
2. If (MRR is medium) and (Ra is low) then (MPCI is small)
3. If (MRR is high) and (Ra is low) then (MPCI is medium)
4. If (MRR is low) and (Ra is medium) then (MPCI is small)
5. If (MRR is medium) and (Ra is medium) then (MPCI is medium)
6. If (MRR is high) and (Ra is medium) then (MPCI is large)
7. If (MRR is low) and (Ra is high) then (MPCI is medium)
8. If (MRR is medium) and (Ra is high) then (MPCI is large)
9. If (MRR is high) and (Ra is high) then (MPCI is very large)

Subsequently, normalized values of (S/N ) ratios at 9 different experimental conditions were obtained (Table7).

Normalized values (Table7) were used during simulation in fuzzy inference system using MATLAB software. For, simulation work, 9 different rules were chosen to emphasize higher production rate and better surface quality. MPCIs obtained at 9 different experimental conditions during simulation were converted to (S/N) ratios (table8) to form the mean response values (Table9). Simulation result of experiment number 7 is shown in fig 7.

Finally main effects plots (Fig.8) considering data mean for (S/N) ratios were obtained to find out the optimality condition.

**TABLE 7: Normalised S/N ratios**

| Sl No | Normalised S/N ratios for MRR | Normalised S/N ratios for surface roughness |
|---|---|---|
| 1 | 0 | 1 |
| 2 | 0.4620 | 0.4963 |
| 3 | 0.7963 | 0.2605 |
| 4 | 0.5527 | 0.6592 |
| 5 | 0.5538 | 0.3691 |
| 6 | 0.5570 | 0.6620 |
| 7 | 0.8774 | 0.6211 |
| 8 | 0.5539 | 0 |
| 9 | 1 | 0.6686 |

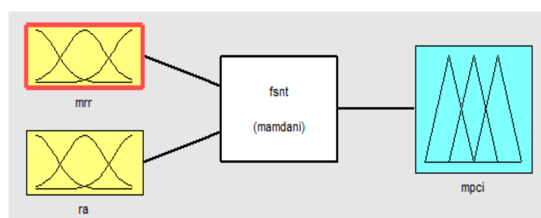



**Fig. 3. Membership functions for input and output parameters in FIS**

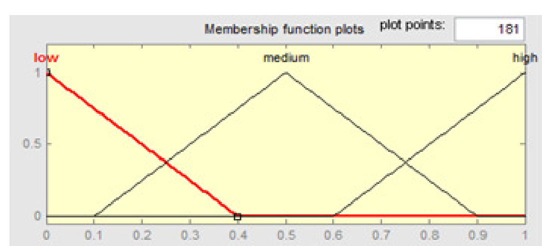



**Fig. 4. Membership functions for mrr**

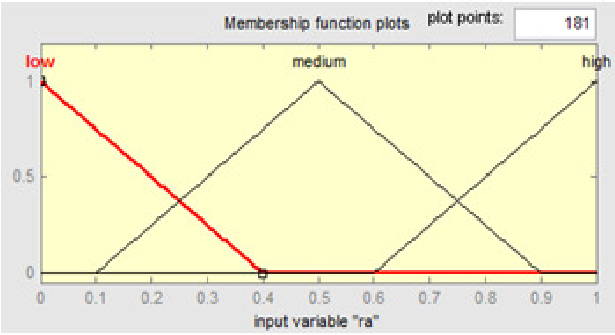



**Fig. 5. Membership functions for $R_a$**

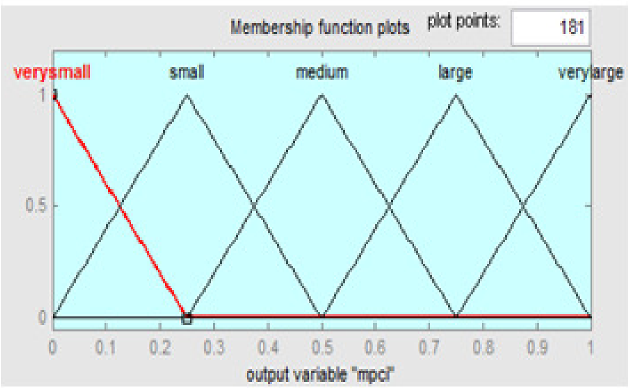



**Fig. 6. Membership functions for MPCI**

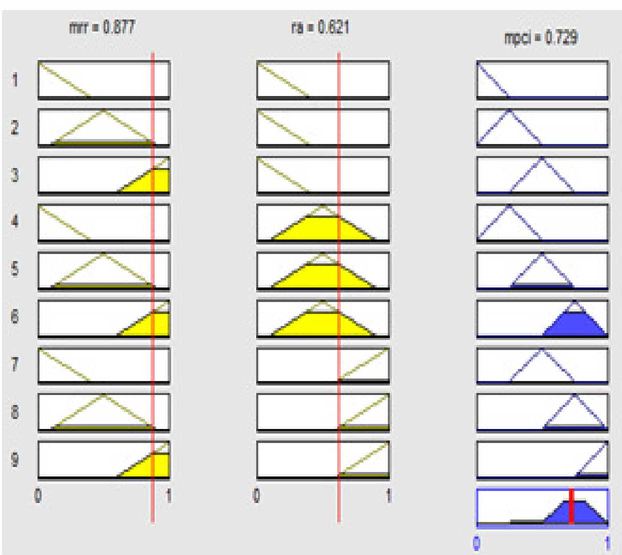



**Fig. 7. Simulation result for experiment number 7**

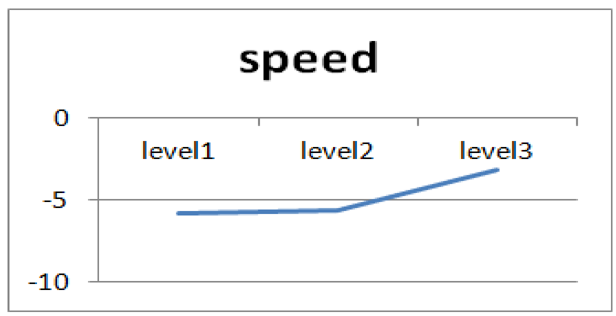
Table 8 shows the results after simulation using FIS in MATLAB.

**TABLE 8: FIS simulation**

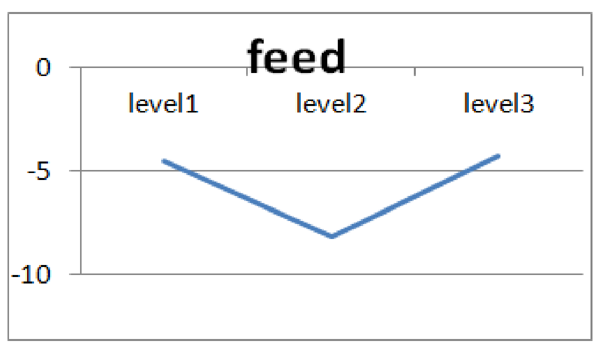
| Sl No | MPCI | S/N ratio for MPCI |
|---|---|---|
| 1 | 0.5 | -6.0206 |
| 2 | 0.5 | -6.0206 |
| 3 | 0.535 | -5.4329 |
| 4 | 0.553 | -5.1455 |
| 5 | 0.471 | -6.5396 |
| 6 | 0.556 | -5.0985 |
| 7 | 0.729 | -2.7454 |
| 8 | 0.25 | -12.0412 |
| 9 | 0.755 | -2.4411 |

**TABLE 9: Mean response table**

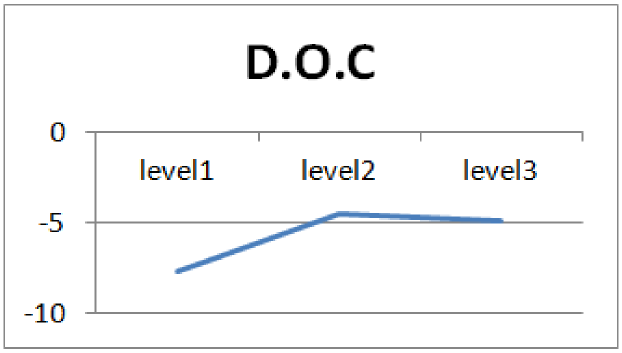
| Level | Speed | Feed | D.O.C |
|---|---|---|---|
| 1 | -5.8247 | -4.5548 | -7.7201 |
| 2 | -5.5945 | -8.2004 | -4.5357 |
| 3 | -5.7425 | -4.3241 | -4.9059 |




**(a)**




**(b)**




**(c)**

**Fig. 8. Main effect plot for speed, feed and DOC.**

Higher (S/N) ratios in the main effect plot (Fig. 8) show the optimal setting of process parameters. From main effect data plot ( Fig. 8a Fig.8b Fig. 8c) and mean response table 9 , it is seen that the optimal condition is attained with experiment number 9 that is (3 3 2) implying v=110 mm/min, f= 0.16mm/rev and d=1mm.

## 5. CONCLUSION

The percentage contribution of each input parameter is found to be significant and each input parameter shows significant influence on the manufacturing of the item when maximization of MRR is considered.

The Percentage contribution of feed is found to be significant for $R_a$ minimization consideration. Amongst all input parameters feed shows better influence on manufacturing of items when minimization of surface roughness is considered.

Considering both MRR and surface roughness, the Taguchi Fuzzy decoupled simulation indicated (3 3 2) as an optimal setting of input process parameters, i.e. optimal setting is attainable for v=110 m/min, f=0.16mm/rev and d=1mm.

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