# MULTI OBJECTIVE OPTIMIZATION OF MACHINING PARAMETERS FOR TURNING USING FUZZY LOGIC AND GENETIC ALGORITHM

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***Abstract :*** Optimization of machining parameters is an important research tool for achievement of higher productivity and production of high-quality products so that market share can be retained and improved in the current competitive scenario. This research aims at multi-objective optimization of turning process on C45 grade medium carbon steel using carbide tool for an optimal parametric combination to provide the minimum Surface Roughness ($R_a$) with the maximum Material Removal Rate (MRR) using the Genetic Algorithms. Turning parameters considered are cutting speed, feed rate and depth of cut. Eighteen experimental runs based on Taguchi's $L_{18}$ ($3^3$x$2^1$) orthogonal array were performed followed by the Response Surface Method (RSM) to model the problem. The significance of chosen parameters on overall quality characteristics of the cutting process has been analyzed by Response Surface method (RSM). Genetic Algorithm is used for optimizing multi-response problem. The optimal parameter values obtained during the study have been validated by confirmation experiment.

***IndexTerms* - Multi objective Optimization, Taguchi's fractional factorial experiments, Random Surface Methodology (RSM), Genetic algorithm, Fuzzy goal programming.**

## I. INTRODUCTION

Reducing production cost and achieving desired quality of product is never fulfilled and continuous research work is being done to determine the optimal cutting parameters to achieve the above goals. In turning process Material Removal Rate (MRR) is considered as one of the factor that directly affects the rate of production, hence there by cost. Minimizing Surface roughness (Ra) is the most important technical requirement for achieving the desired surface quality which affects the functional behavior of a mechanical component. Both MRR and surface roughness are influenced by various factors like cutting speed, feed, depth of cut and nose radius of tool. Many researchers have studied the effects of optimal selection of machining parameters in turning.

Tzeng and Chen (2006) [1] applied grey relational analysis to optimize the process parameters in turning of tool steels. They conducted Taguchi experiments with eight independent variables and the optimum turning parameters were determined based on grey relational grade which maximizes the accuracy and minimizes the surface roughness and dimensional precision.

M Kaladhar et al. (2010) [2] conducted experiments on AISI 202 austenitic stainless steel using CVD coated cemented carbide tools and the process parameters such as speed, feed, depth of cut and nose radius are used to explore their effect on the surface roughness (Ra) of the work piece. Various methods used for experimentation and analysis are Design of Experiments and ANOVA. From their analysis, it was observed that the feed is the most significant factor that influences the surface roughness followed by nose radius. An attempt has been made to generate prediction models for surface roughness.

Qi Yue and Shan Liang (2011)[3] used genetic algorithm for optimization of two-dimensional sheet metal nesting design and explained that genetic algorithm is a numerical method for global optimization instead of local optimization and is more suitable for solving large scale discrete optimization problems.

Milon D Selvam et al. (2012)[4] described the use of Taguchi technique and genetic algorithm for minimizing the surface roughness in machining mild steel with three zinc coated carbide tools inserted into a face miller of 25 mm dia. The experiments were planned using Taguchi's experimental design technique. The machining parameters used are number of passes, depth of cut, spindle speed and feed. The effect of machining parameters on surface roughness was evaluated and the optimum cutting condition for minimizing the surface roughness is determined.

## 2. EXPERIMENTAL PROCEDURE

### 2.1 Machining Conditions

Experiments are performed on MORI SEIKI CNC lathe machine. Test samples are medium carbon steel bars of grade C45 with 32 mm in diameter and 100 mm in length. Chemical composition of DIN C45 steel are given in Table 1. Experiments were carried out by the two external machining turning tool with the holder mark DDJNL 3225P15 and the tungsten carbide insert under wet cutting conditions. The tool nose radii are 0.4 mm and 0.8 mm. Mitutoyo SJ-301 Surface roughness tester is used for measurement. Material Removal Rate can be found by measuring the initial and final diameters of the work piece with 203ernier caliper, time taken for machining by stop watch and calculating using formula

$$M.R.R= \frac{\pi}{4}(D_1^2-D_2^2).L / T$$

**Table 1: Composition of C45 Grade steel**

| | C | Si | Mn | Ni | Mo | Cr+Mo+Ni |
|---|---|---|---|---|---|---|
| Min | 0.42 | | 0.5 | | | |
| Max | 0.50 | 0.40 | 0.80 | 0.40 | 0.10 | 0.63 |

**2.2 Design of Experiments**:

Design of experiments is a useful tool for creating a systematic experimentation plan and arriving a meaningful conclusion without being inundated in huge set of experimental data. The effects of multiple factors are studied simultaneously in DOE by running tests at various levels of factors. Taguchi's method uses a special design of orthogonal arrays to study the entire parameter space with limited number of experiments(18). The experiments have been carried out by using standardized Taguchi based experimental design, a $L_{18}$ ($3^3$x$2^1$) orthogonal arrays, with three levels for three cutting parameters namely spindle speed, feed and depth of cut and two levels for one parameter namely nose radius. The controlled parameters and their levels are presented in table 2

**Table 2: Controlled parameters for turning on CNC lathe**

| **Parameters** | **Levels** | | |
|---|---|---|---|
| | **1** | **2** | **3** |
| Spindle speed | 2500 | 3000 | 3500 |
| Feed (mm/rev)-B | 0.1 | 0.15 | 0.2 |

The necessary number of test runs is eighteen. The experimental results along with Taguchi's orthogonal array are shown in table 3

| **Runs** | **A** | **B** | **C** | **D** | **$R_a$** | **MRR** |
|---|---|---|---|---|---|---|
| 1 | 0.4 | 2500 | 0.1 | 0.4 | 0.79 | 9.95 |
| 2 | 0.4 | 2500 | 0.15 | 0.8 | 1.76 | 29.86 |
| 3 | 0.4 | 2500 | 0.2 | 1.2 | 2.73 | 59.72 |
| 4 | 0.4 | 3000 | 0.1 | 0.4 | 0.95 | 11.94 |
| 5 | 0.4 | 3000 | 0.15 | 0.8 | 1.75 | 35.83 |
| 6 | 0.4 | 3000 | 0.2 | 1.2 | 2.60 | 71.66 |
| 7 | 0.4 | 3500 | 0.1 | 0.8 | 0.95 | 27.86 |
| 8 | 0.4 | 3500 | 0.15 | 1.2 | 1.77 | 62.70 |
| 9 | 0.4 | 3500 | 0.2 | 0.4 | 2.56 | 27.86 |
| 10 | 0.8 | 2500 | 0.1 | 1.2 | 0.52 | 29.86 |
| 11 | 0.8 | 2500 | 0.15 | 0.4 | 0.77 | 14.93 |
| 12 | 0.8 | 2500 | 0.2 | 0.8 | 1.42 | 39.81 |
| 13 | 0.8 | 3000 | 0.1 | 0.8 | 0.73 | 23.88 |
| 14 | 0.8 | 3000 | 0.15 | 1.2 | 1.04 | 53.74 |
| 15 | 0.8 | 3000 | 0.2 | 0.4 | 1.47 | 23.88 |
| 16 | 0.8 | 3500 | 0.1 | 1.2 | 0.81 | 41.80 |
| 17 | 0.8 | 3500 | 0.15 | 0.4 | 1.18 | 20.90 |
| 18 | 0.8 | 3500 | 0.2 | 0.8 | 1.52 | 55.73 |

**3. RESULTS AND DISCUSSION**:

**3.1 Analysis of response parameters**: The analysis of results is done using Response Surface Methodology by Minitab software and the following conclusions are made.

**3.2 Analysis of $R_a$:**The analysis of Ra by RSM using Minitab software is presented in table 4

| Term | Coef | P |
|---|---|---|
| Constant | -2.948 | 0.09 |
| A | -0.59 | 0.486 |
| B | 0.0009 | 0.308 |
| C | 28.588 | 0.008 |
| D | 1.0445 | 0.162 |
| B*B | 0 | 0.439 |
| C*C | 13.536 | 0.374 |
| D*D | -0.094 | 0.68 |
| A*B | 0.0007 | 0.025 |
| A*C | -21.46 | 0.001 |
| A*D | -0.079 | 0.816 |
| B*C | -0.002 | 0.084 |
| B*D | -2E-04 | 0.141 |
| C*D | -0.513 | 0.78 |

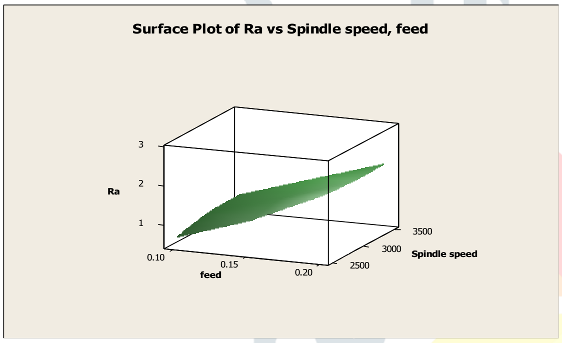


Fig 1: Surface plot of $R_a$ vs Spindle speed and feed

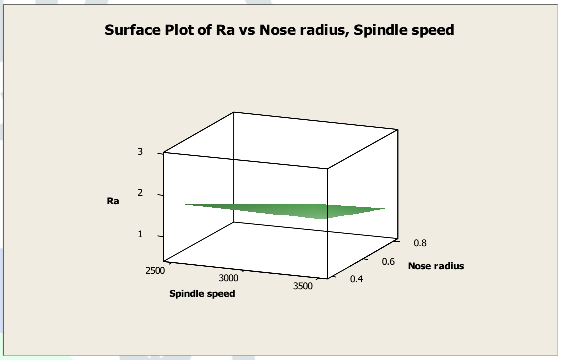


Fig 2: Surface plot of $R_a$ vs Spindle speed and nose radius

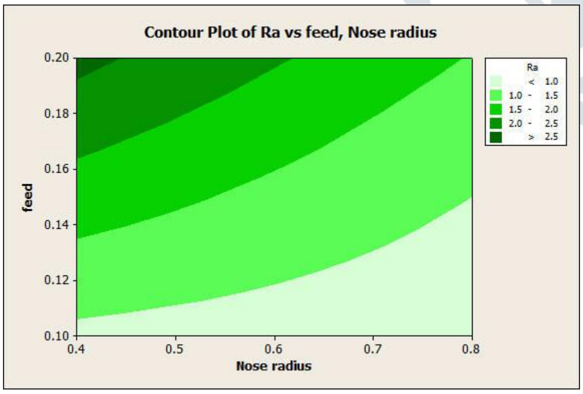


Fig 3: Contour plot of $R_a$ vs feed and nose radius

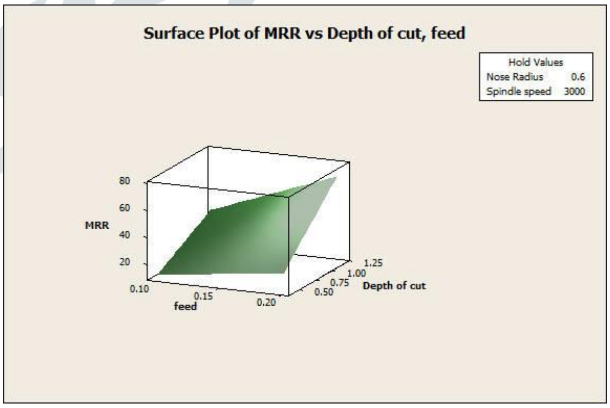


**Fig. 4 Surface plot of MRR vs depth of cut and feed**

It is evident from the analysis in table 4 and Fig 1, 2 and 3 that the effect of feed is more on surface roughness than any other parameters considered. It is also found that there is significant effect of interference between nose radius and spindle speed as well as nose radius and feed. The Value of $R_a$ increases with increase in nose radius. At higher feeds surface roughness decrease with depth of cut to some extent and then increases because of interference.

### 3.3 Analysis of MRR:

**Table 5: Analysis of MRR using RSM**

| Term | Coef | P |
|---|---|---|
| Constant | 22.969 | 0.055 |
| A | 6.045 | 0.291 |
| B | -0.005 | 0.382 |
| C | -279.4 | 0.002 |
| D | -34.35 | 0.001 |
| B*B | 0 | 0.267 |
| C*C | -70.82 | 0.464 |
| D*D | -1.107 | 0.464 |
| A*B | -0.002 | 0.148 |
| A*C | 30.945 | 0.135 |
| A*D | -3.868 | 0.135 |
| B*C | 0.093 | 0 |
| B*D | 0.013 | 0 |
| C*D | 294.78 | 0 |

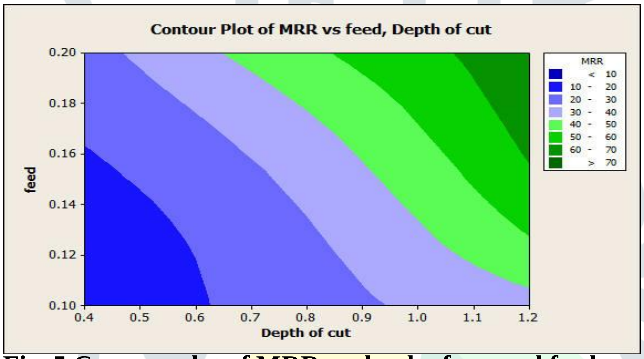


**Fig..5 Contour plot of MRR vs depth of cut and feed**

From the above analysis in table 5 and Fig 4 and 5 it is clear that feed and depth of cut are the most influencing factors on Material Removal Rate and there is considerable impact of interference effect among Cutting speed, feed and depth of cut. Also the value of MRR increases with increase in feed and depth of cut. It his high at higher feed and depth of cuts due to interference effects. From the Contour plot in Fig 5 it is clear that at lower values of feed and depth cut MRR is low but it increases with the increase in depth cut and feed.

## 4.0 MODELLING OF RESULTS:

The results are modeled using Response Surface Methodology and the following equations are obtained for MRR and $R_a$.

### 4.1 Equation for MRR :

MRR=-(22.969+6.045*A-0.005*B-279.366*C-34.347*D+0.0*B^2-70.822*C^2-1.107*D^2-0.002*A*B+30.945*A*C-3.868*A*D +0.093*B*C+0.013*B*D+294.775*C*D)

### 4.2 Equation for Surface roughness ($R_a$);

$R_a$=(-2.9481-0.5879*A+0.0009*B+28.5879*C+ 1.0445*D-0.0*B^2+13.5355*C^2-0.0939*D^2+ 0.0007*A*B-21.4557*A*C-0.0794*A*D-0.0024*B*C-0.0002*B*D-0.5128*C*D)

## 5.0 OPTIMIZATION OF PARAMETERS:

Based on the model obtained, the above equations are optimized using Genetic Algorithm (GA). GA is more robust than conventional optimization techniques and it doesn't break even the inputs changed slightly or in presence of noise. The optimum values arrived from GA are not confined to local optima. Results were obtained to global optima.

In this research the design parameters are optimized using Genetic Algorithm in MAT Lab. Code is written for fitness function of each response variable and constraints. GA function is used to optimize the design parameters for a particular response variable. Both the equations are optimized separately using unconstrained genetic algorithm. Lower bounds and upper bounds were obtained for each response variable and then the problem is converted into single objective constrained optimization problem using Fuzzy goal programming. The above single objective constrained optimization problem is again solved using genetic algorithm in the similar procedure discussed above.

### 5.1 Optimum values for $R_a$:

The values of design parameters obtained from Genetic Algorithm for optimum values of $R_a$ are presented in table 6 and ploted in Fig. 6

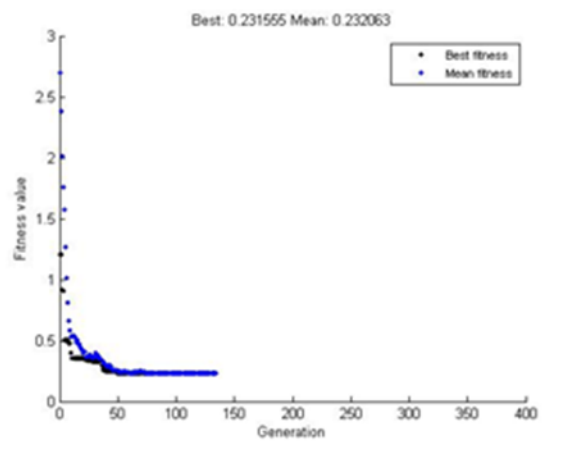


Fig 6 Fitness value plot for $R_a$

**Table 6: Optimum value of parameters for $R_a$**

| | Nose radius | Spindle speed | feed | depth of cut | $R_a$ |
|---|---|---|---|---|---|
| Calculated | 0.8 | 2500 | 0.1 | 0.1 | 0.2315 |
| Confirmatory experiment | 0.8 | 2500 | 0.1 | 0.1 | 0.27 |

**6.5.2 Optimum values for MRR:**

The values of design parameters obtained from Genetic Algorithm for optimum values of MRR is presented in table 7 and plotted in Fig. 7

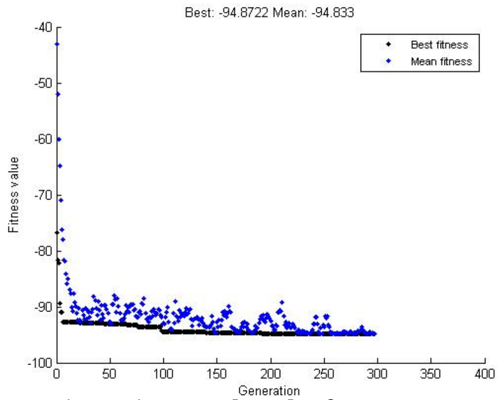


**Fig. 7 Fitness value plot for MRR**

**Table 7 Optimum value of parameters for MRR**

| | Nose radius | Spindle speed | feed | depth of cut | MRR |
|---|---|---|---|---|---|
| Calculated | 0.8 | 3500 | 0.2 | 1.2 | 94.8722 |
| Confirmatory experiment | 0.8 | 3500 | 0.2 | 1.2 | 88.23 |

MRR is calculated with the design variables at minimum surface roughness condition and Ra is calculated with the design variables at maximum MRR condition as presented in table 8

**Table 8 : Values of parameters for $R_a$ and MRR at optimum conditions**

| | Nose radius | Spindle speed | Feed | Depth of cut | Ra | MRR |
|---|---|---|---|---|---|---|
| Calculated | 0.8 | 2007.2 | 0.101 | 0.355 | 0.491 | 13.37 |
| Confirmatory experiment | 0.8 | 2007 | 0.1 | 0.35 | 0.55 | 12.15 |

Now lower bounds and upper bounds were calculated as shown in table 9 for formulating a constrained single objective optimization problem using fuzzy goal programming.

**Table 9: Lower and Upper bounds for Ra and MRR**

| | Ra | MRR |
|---|---|---|
| Lower bound | 0.2314 | 8.42832 |
| Upper bound | 0.5 | 100 |

Upper bounds were modified keeping in view of practical considerations with and with the intention of minimizing the value of Ra and maximizing the value of MRR.

Now membership functions are formed using

$\mu\ (SR) = \frac{UB-Ra}{UB-LB}$ $\mu\ (MRR) = \frac{MRR-LB}{UB-LB}$

Now the problem is formulated as

Maximize $\lambda$

Subject to $\lambda \leq \mu(Ra)$

$\lambda \leq \mu(MRR)$

where $\lambda$ is the aspiration level

So the constraints are

$\lambda \leq \frac{0.5-Ra}{0.5-0.2314}$ $\lambda \leq \frac{MRR-8.43}{100-8.43}$

After converting to inequality constraints in MAT lab format.

**Inequality constraint 1:**

ƛ *(100-8.428)-(22.969+6.045*A-0.005*B-279.366*C- 34.347*D-70.822*C^2-1.107*D^2-0.002*A*B+30.945*A*C-3.868*A*D+ 0.093*B*C+0.013*B*D+294.775*C*D-8.428) ≤ 0

**Inequality constraint 2:**

ƛ *(0.5-0.2314)-(0.5-(-2.9481-0.5879*A+0.0009*B+28.5879*C+ 1.0445*D-0.0*B^2+13.5355*C^2-0.0939*D^2+0.0007*A*B-21.4557*A*C-0.0794*A*D-0.0024*B*C-0.0002*B*D-0.5128*C*D ≤ 0

The above problem is solved as constrained single objective optimization problem using Genetic Algorithm tool in MAT lab and best solution is presented in Table 10

**Table 10 Optimum values of Ra and MRR after multi-objective optimization**

| Nose radius | Spindle speed | feed | depth of cut | Ra | MRR |
|---|---|---|---|---|---|
| 0.8 | 2500 | 0.1 | 0.1 | 0.2315 | 8.4283 |
| 0.8 | 3500 | 0.2 | 1.2 | 2.9149 | 94.872 |

**6.0 RESULTS:**

The optimum conditions provide the best performance based on the data obtained from the experiments and various methods used for optimization.

**Surface Roughness(Ra)**

| | | |
|---|---|---|
| Nose radius | : | 0.8 mm |
| Spindle speed | : | 2500 RPM |
| Feed | : | 0.1 mm |
| Depth of cut | : | 0.1 mm |

**Material removal rate**

| | | |
|---|---|---|
| Nose radius | : | 0.8 mm |
| Spindle speed | : | 3500 RPM |
| Feed | : | 0.2 mm |
| Depth of cut | : | 1.2 mm |

**Surface Roughness (Ra) and MRR:**

| | | |
|---|---|---|
| Nose radius | : | 0.8 mm |
| Spindle speed | : | 2007 RPM |
| Feed | : | 0.1 mm |
| Depth of cut | : | 0.355 mm |

**7.0 CONCLUSIONS:**

Based on the results obtained and discussion made in the previous chapters the following conclusions are made.

1. By using the Taguchi fractional factorial experiments the number of experiments is drastically reduced.
2. The results of RSM indicate that the effect of feed is more on surface roughness than any other parameters considered.
3. It is found that there is significant effect of interference by nose radius and spindle speed as well as nose radius and feed.
4. The value of Ra increases with increase in nose radius.
5. At higher feeds surface roughness decrease with depth of cut to some extent and then increases.
6. MRR increases with spindle speed, feed and depth of cut. But depth of cut has highest influence on MRR than any other followed by feed.
7. There is considerable effect of interaction among cutting speed, feed and depth of cut.
8. By using genetic algorithm as optimization technique the optimum values arrived not confined to local optima. Results were obtained to global optima.
9. Fuzzy goal programming is a helpful tool for converting multi objective optimization problem to single objective optimization problem.

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