# Optimization in Cylindrical Grinding of Stainless Steel (SS 410) Shaft using Taguchi Method and Principal Component Analysis

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***Abstract*: This research is done to optimize cylindrical grinding operation using four process parameters as Job Speed, Feed Depth of Cut (DOC) and Grinding Wheel. The two main objectives for optimization are Material Removal Rate (MRR) and Surface Roughness. The experiments are designed using Taguchi method, along with Principal Component Analysis (PCA) to formulate the results. The grinding operations are conducted on Stainless Steel (SS 410) Shaft. Thus, the process parameters are experimentally investigated in order to minimize Surface Roughness (RA) and maximize Material Removal Rate (MRR) simultaneously.**

***Keywords*: Depth of Cut (DOC), Grinding Wheel, Material Removal Rate (MRR), Surface Roughness (RA), Taguchi Method, Principal Component Analysis (PCA)**

## Introduction

### Cylindrical Grinding Process:

Cylindrical grinding is the process of final finishing of components required for smooth surfaces and close tolerances. During the cylindrical grinding operations very small size of the chips are produced. It is widely used in industry, grinding remains perhaps the least understood of all machining processes [1]. The major operating input parameters that influence the output response of surface roughness are:

1. Machine parameter
2. Process parameter
3. Grinding wheel parameter
4. Work piece parameter

The Cylindrical grinder is a type of grinding machine use to shape the outside of an object. The cylindrical grinder can work on a variety of shapes; however, the object must have a central axis of rotation. The Grinding machine used in our experiment is the Cylindrical Grinding Machine.

The Cylindrical Grinding is defined is having four essential actions.

1. The work (object) must be constantly rotating.
2. The grinding wheel must be constantly rotating.
3. The grinding wheel is fed towards and away from the work.
4. Either the work or the grinding wheel is traversed with respect to other.

### Details of stainless steel SS 410:

Grade 410 stainless steels are general-purpose martensitic stainless steels containing 11.5% chromium, which provide good corrosion resistance properties.

**Different Properties of Stainless Steel 410**

**Table 1: Composition ranges of grade 410 stainless steel**

| Grade | | C | Mn | Si | P | S | Cr | Ni |
|---|---|---|---|---|---|---|---|---|
| 410 | Min. | - | - | - | - | - | 11.5 | 0.75 |
| | Max. | 0.15 | **1** | 1 | 0.04 | 0.03 | 13.5 | |

**Table 2: Mechanical properties of grade 410 stainless steel**

| Tempering Temperature (°C) | Tensile Strength (MPa) | Yield Strength 0.2% Proof (MPa) | Elongation (% in 50 mm) | Hardness Brinell (HB) | Impact Charpy V (J) |
|---|---|---|---|---|---|
| Annealed * | 480 min | 275 min | 16 min | - | - |
| 204 | 1475 | 1005 | 11 | 400 | 30 |
| 316 | 1470 | 961 | 18 | 400 | 36 |
| 427 | 1340 | 920 | 18.5 | 405 | # |
| 538 | 985 | 730 | 16 | 321 | # |
| 593 | 870 | 675 | 20 | 255 | 39 |
| 650 | 300 | 270 | 29.5 | 225 | 80 |

**Literature Review**

**Prediction and Optimization of Cylindrical Grinding Parameters for Surface Roughness Using Taguchi Method - M. Ganesan, S. Karthikeyan& N. Karthikeyan [1]:** Recently 304 stainless steel finds many applications like Automotive, Aerospace, Nuclear, Chemical and Cryogenics. The cylindrical grinding parameters on 304 stainless steel are conducted using Taguchi design of experiments of L9 orthogonal array was selected with 3 levels with 3 factors and output parameter of Surface Roughness is measured.

**Review of Analysis & Optimization of Cylindrical Grinding Process Parameters on Material Removal Rate of En15AM - Sandeep Kumar &Onkar Singh Bhatia [3]:** Grinding process is surface finishing process generally used to smoothen the surfaces by removing the limited quantity of material from the already machined surfaces. Cylindrical grinding or abrasive machining is the most popular machining process of removing metal from a work piece surface in the form of tiny chips by the action of irregularly shaped abrasive particles.

**Multi Objective Optimization in Turning of EN25 Steel Using Taguchi Based Utility Concept Coupled with Principal Component Analysis - B.Singarvela, T.Selvarajb, R.Jeyapaul [5]:** In multi-objective optimization, weight criteria of each objective is important for producing better and accurate solutions. In this experimental analysis the optimum machining parameters are estimated using Taguchi based utility concept coupled with Principal Component Analysis (PCA) on turning of EN25 steel with CVD and PVD coated carbide tools.

**Problem Definition**

The problem faced by the company was that they were not able to achieve their monthly target, if the order size was increased. So the identification of process parameter having highest impact on MRR and surface finish i.e. to improve the MRR and to maintain the surface finish, thus improving the overall productivity in the grinding operation.

**Objective**

The main objective of this report is to improve "Material Removal Rate (MRR)" and reduce "Surface Roughness", for design of experiment Taguchi's Design of Experiment Method is used.

**Methodology:**

Process Parameters:

A) **Job Speed:** The revolution of job per minute. The job is held between two center using carrier plates.
B) **Feed Rate:** Feed rate is the velocity at which the work-piece is fed, i.e., advanced against the grinding wheel.
C) **Depth of Cut (DOC):** DOC is the total amount of metal removed per pass of grinding wheel.
D) **Grinding Wheel:** It is a tool used for metal finishing operation.

**Designing an experiment:**

The design of an experiment involves the following steps

1. Selection of independent variables
2. Selection of number of level settings for each independent variable
3. Selection of orthogonal array
4. Assigning the independent variables to each column
5. Conducting the experiments
6. Analyzing the data
7. Inference

**Analysis of Variance (ANOVA):**

ANOVA is used to investigate the significant effect of machining parameters on responses. The ANOVA table contains the degrees of freedom, sum of squares, mean square and percentage contribution. The parameters with higher percentage contribution arc ranked higher in terms of importance in the experiment and also have significant effects in controlling the overall response. ANOVA is also needed for estimating the error variance in the process.

**Experimental Procedure And Analysis**
**Taguchi's Design of Experiment:**

**Table 3: Results of experiment**

| Exp. No. | Job Speed (RPM) | Feed Rate (mm/sec) | DOC (µm) | Wheel | MRR (gm/sec) | RA (µm) |
|---|---|---|---|---|---|---|
| **1** | 60 | 2 | 5 | Black | 0.012121 | 0.413 |
| **2** | 60 | 4.5 | 10 | White | 0.042075 | 0.461 |
| **3** | 60 | 7 | 15 | Pink | 0.143520 | 0.810 |
| **4** | 120 | 2 | 10 | Pink | 0.031884 | 0.502 |
| **5** | 120 | 4.5 | 15 | Black | 0.039246 | 1.007 |
| **6** | 120 | 7 | 5 | White | 0.106571 | 1.737 |
| **7** | 230 | 2 | 15 | White | 0.055935 | 1.238 |
| **8** | 230 | 4.5 | 5 | Pink | 0.091358 | 0.656 |
| **9** | 230 | 7 | 10 | Black | 0.078277 | 1.450 |

**Principal Component Analysis (PCA) Calculations:**
From the above equations (1) to (9):

**Step 1: Normalization of the responses:**

**Table 4: Values of S/N Ratio and Normalized S/N Ratio**

| Exp no. | Levels | | | | Outputs | | S/N Ratio | | Normalized S/N Ratio | |
|---|---|---|---|---|---|---|---|---|---|---|
| | X1 | X2 | X3 | X4 | Y1 | Y2 | Y1 | Y2 | Y1 | Y2 |
| **1** | 1 | 1 | 1 | 1 | 0.012121 | 0.413 | -38.33 | 7.68 | 0.00 | 1.00 |
| **2** | 1 | 2 | 2 | 2 | 0.042075 | 0.461 | -27.52 | 6.73 | 0.50 | 0.92 |
| **3** | 1 | 3 | 3 | 3 | 0.14352 | 0.81 | -16.86 | 1.83 | 1.00 | 0.53 |
| **4** | 2 | 1 | 2 | 3 | 0.031884 | 0.502 | -29.93 | 5.99 | 0.39 | 0.86 |
| **5** | 2 | 2 | 3 | 1 | 0.039246 | 1.007 | -28.12 | -0.06 | 0.48 | 0.38 |
| **6** | 2 | 3 | 1 | 2 | 0.106571 | 1.737 | -19.45 | -4.80 | 0.88 | 0.00 |
| **7** | 3 | 1 | 2 | 2 | 0.055935 | 1.238 | -25.05 | -1.85 | 0.62 | 0.24 |
| **8** | 3 | 2 | 1 | 3 | 0.091358 | 0.656 | -20.79 | 3.66 | 0.82 | 0.68 |
| **9** | 3 | 3 | 3 | 1 | 0.078277 | 1.45 | -22.13 | -3.23 | 0.75 | 0.13 |
| **Minimum** | | | | | | | -38.33 | -4.80 | | |
| **Maximum** | | | | | | | -16.86 | 7.68 | | |
| **Difference** | | | | | | | 21.47 | 12.48 | | |

**Step 2: Checking for correlation between two quality characteristics: Table 5: Calculation of Eigen values and Eigen Vectors**

| **Σ** | 0.30 | 0.36 |
|---|---|---|
| **Covariance** | -0.0616 | |
| **R12** | -0.5566 | |

| | Y1 | Y2 |
|---|---|---|
| **Y1** | 1 | -0.5566 |
| **Y2** | -0.5566 | 1 |

| | | X1 | X2 |
|---|---|---|---|
| **λ1** | 1.5566 | -0.7071 | 0.7071 |
| **λ2** | 0.4434 | -0.7071 | -0.7071 |
| **Sum** | 2 | | |

| | |
|---|---|
| **ek** | 0.778 |
| | 0.222 |

**Step 3: Calculation of the principal component score:**

**Result obtained from PCA:**

| | L1 | L2 | L3 | Optimum Combination |
|---|---|---|---|---|
| **X1** | -0.098 | -0.746 | -1.140 | 1 |
| **X2** | 0.112 | -0.491 | -1.604 | 1 |
| **X3** | -0.540 | -0.275 | -1.169 | 2 |
| **X4** | -0.278 | -0.959 | -0.746 | 1 |

**Analysis of Variance (ANOVA):**

**ANOVA of MRR**

| | df | SS | MS | F | Significance F |
|---|---|---|---|---|---|
| **Regression** | 4 | 0.011960445 | 0.002990111 | 6.166528841 | 0.052978401 |
| **Residual** | 4 | 0.001939575 | 0.000484894 | | |
| **Total** | 8 | 0.01390002 | | | |

**ANOVA of Surface Roughness (RA)**

| | df | SS | MS | F | Significance F |
|---|---|---|---|---|---|
| **Regression** | 4 | 1.179476968 | 0.294869242 | 1.959749015 | 0.265323826 |
| **Residual** | 4 | 0.601851032 | 0.150462758 | | |
| **Total** | 8 | 1.781328 | | | |

**Regression Statistics of MRR and RA**

| | MRR | Ra |
|---|---|---|
| **Multiple R** | 0.927611143 | 0.813715868 |
| **R Square** | 0.860462433 | 0.662133514 |
| **Adjusted R Square** | 0.720924866 | 0.324267027 |
| **Standard Error** | 0.022020303 | 0.387895293 |
| **Observations** | 9 | 9 |

As per ANOVA results R Square for MRR = 86.05% and R Square for Ra = 66.21%

**Result and Conclusion**

From the experimental work carried out following:

- As per orthogonal array nine number of experiments were conducted.
- As per PCA Level 1 of Job Speed, Level 1 of Feed, Level 2 of DOC and Level 1 of Grinding wheel are the optimum levels.
- As per the PCA results the best combination for optimum MRR and Surface Roughness is:
  - Job Speed = **60 rpm**, Feed Rate = **2 mm/s**, DOC = **10 µm**, Grinding Wheel = **Black** MRR **= 0.02142 gm/sec**, Surface Roughness = **0.533 µm**
- Considering both the outputs simultaneously the R square value of MRR and Ra are 86.05% and 66.21% respectively.
- As per Table Result of Experiment if MRR is preferred then combination of Experiment number 8 gives optimum value, i.e.:
  - Job Speed = **230 rpm**, Feed Rate = **4.5 mm/s**, DOC = **5 µm**, Grinding Wheel = **Pink**
- As per Table Result of Experiment if Ra is preferred then combination of Experiment number 1 gives optimum value, i.e.:
  - Job Speed = **60 rpm**, Feed Rate = **2 mm/s**, DOC = **5 µm**, Grinding Wheel = **Black**

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