# Effect of Cutting Parameters on MRR and Surface Roughness in Turning of Aluminium (6061)

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**Abstract**

The work and study presented aims to investigate the effect of the rake angles and cutting parameters (cutting speed, feed rate and depth of cut) on material removal rate (MRR) and surface roughness, in turning of Aluminium (6061) in dry condition. The cutting tools were prepared with positive Rake angles $2^0$, $3^0$, $4^0$ .The effect of cutting condition (cutting speed and feed rate) on MRR and surface roughness were studied and analyzed while depth of cut kept constant as 0.2 mm. Design of experiments (DOE) were conducted for the analysis of the influence of the turning parameters on the surface roughness by using Taguchi design and then followed by Analysis of Variance (ANOVA) to find the maximum MRR and minimum surface roughness.

## 1. Introduction

Surface roughness is mainly a result of process parameters such as

1. Tool Geometry
   - Nose Radius,
   - Edge Geometry,
   - Rake Angle
2. Cutting Conditions
   - Feed Rate,
   - Cutting Speed,
   - Depth Of Cut

Surface roughness is harder to attain and track than physical dimensions are, because relatively many factors affect surface roughness. Some of these factors can be controlled and some cannot. Controllable process parameters include feed, cutting speed, tool geometry, and tool setup. Other factors, such as tool, work piece and machine vibration, tool wear and degradation, and work piece and tool material variability cannot be controlled as easily. The important cutting parameters discussed here are cutting speed, feed and depth of cut. Proper selection of cutting parameters and tool can produce longer tool life and lower surface roughness.

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In this paper Taguchi's (DOE) approach is used to analyze the effect of process parameters like cutting speed, feed, and depth of cut on Surface Roughness of Aluminium 6061 work material while machining with the cutting tools which were prepared with positive Rake angles 20, 30, 40 and to obtain an optimal setting of these parameters that may result in good surface finish.

Taguchi method is a powerful tool for the design of high quality systems. It provides simple, efficient and systematic approach to optimize designs for performance, quality and cost. Taguchi method is efficient method for designing process that operates consistently and optimally over a variety of conditions. To determine the best design it requires the use of a strategically designed experiment. Taguchi approach to design of experiments in easy to adopt and apply for users with limited knowledge of statistics, hence gained wide popularity in the engineering and scientific community. The desired cutting parameters are determined based on experience or by hand book. Cutting parameters are reflected.

Steps of Taguchi method are as follows:

1. Identification of main function, side effects and failure mode.
2. Identification of noise factor, testing condition and quality characteristics.

3. Identification of the main function to be optimized.
4. Identification the control factor and their levels.
5. Selection of orthogonal array and matrix experiment.
6. Conducting the matrix experiment.
7. Analysing the data, prediction of the optimum level and performance.
8. Performing the verification experiment and planning the future action.

ANOVA can be useful for determining influence of any given input parameter from a series of experimental results by design of experiments for machining process and it can be used to interpret experimental data. Analysis of variance (ANOVA) is a collection of statistical models, and their associated procedures, in which the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether or not the means of several groups are all equal, and therefore generalizes t-test to more than two groups.

ANOVA is used in the analysis of comparative experiments, those in which only the difference in outcomes is of interest. The statistical significance of the experiment is determined by a ratio of two variances. This ratio is independent of several possible alterations to the experimental observations: Adding a constant to all observations does not alter significance. Multiplying all observations by a constant does not alter significance. So ANOVA statistical significance results are independent of constant bias and scaling errors as well as the units used in expressing observations.

Understanding of material removal concept in metal cutting is very important in designing process and cutting tool selection to ensure the quality of the product. The material removal rate (MRR) in turning operations is the volume of material/metal that is removed per unit time in mm3/min. For each revolution of the work piece, a ring shaped layer of material is removed. Therefore, MRR in mm3/min is 1000 Vfd, Where V is cutting speed in mm/min, f is machine feed rate mm/revolution. d is depth of cut.

## 2. Experiment Set Up

The machining trials were carried out on conventional Lathe Machine model Kirloskar Turnmaster-35. The work piece material used was 6061 Aluminum HINDALCO made. The cylindrical work piece was prepared in the form of round bar 50 mm in diameter and 150 mm in length. The machining condition parameters were the cutting speed of 180, 450 and 710 rpm, feed rate of 0.2, 0.315 and 0.4 mm/rev, while the depth of cut (DOC) was kept constant to 0.2 mm. The effect of cutting condition (cutting speed and feed rate) on material removal rate and surface roughness were studied and analyzed. Experiments were conducted based on the Taguchi design of experiments (DOE) with orthogonal L27 array, and then followed by optimization of the results using Analysis of Variance (ANOVA) to find minimum surface roughness and the maximum MRR.

Standardized material were selected to ensure consistency of the alloy, which was a common wrought alloy used in industry 6061 Aluminum HINDALCO made in the form of bars with the size of diameter 50 mm 150 mm length so as to fit under the chuck.

**Table: 1.** Chemical Composition of Aluminum Alloy

| **Element** | **Cu** | **Mg** | **Si** | **Fe** | **Mn** | **Other** |
|---|---|---|---|---|---|---|
| **Weight%** | 0.15-0.4 | 0.7-1.2 | 0.4-0.8 | 0.7 max | 0.2-0.8 | 0.4 |

The aluminum we have chosen for turning is actually a Heat Treatable Alloy manufactured in the form of bars by HINDALCO. This standard structural alloy, one of the most versatile of the heat-treatable alloys, is popular for medium to high strength requirements and has good toughness characteristics. Applications range from transportation components to machinery and equipment applications to recreation products and consumer durables. The different alloying elements present in a work piece are shown in the Table 1.

The surface roughness of machined surface has been measured by a Surface Roughness Measuring instrument, the Surtronic 3+, is a portable, self-contained instrument for the measurement of surface texture and is suitable for use in both the workshop and laboratory. The measurements results are displaced on an LCD screen and can be output to an optional printer or another computer for further results.

| **Code** | **Cutting Parameter** | **Level 1** | **Level 2** | **Level 3** |
|---|---|---|---|---|
| **A** | Rake Angles | $2^0$ | $3^0$ | $4^0$ |
| **B** | Speed ‘s’(rpm) | 180 | 450 | 710 |

| | | | | |
|---|---|---|---|---|
| C | Feed 'f '(mm/rev) | 0.2 | 0.315 | 0.4 |

**Table: 3.** Machine readings and calculations

| Expt. No | Control Factors | | | Rake Angle(a) | Speeds (s) | Feed (f) | Measured Ra | MRR 1 | MRR 2 |
|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | | | | | | |
| | (a) | (s) | (f) | (degrees) | (rpm) | (mm/rev) | (µm ) | (mm$^3$/min ) | (mm$^3$/sec ) |
| 1 | 1 | 1 | 1 | 2 | 180 | 0.2 | 1.04 | 1113.927 | 18.565 |
| 2 | 1 | 1 | 2 | 2 | 180 | 0.315 | 2.44 | 1672.129 | 27.869 |
| 3 | 1 | 1 | 3 | 2 | 180 | 0.4 | 2.06 | 2022.443 | 33.707 |
| 4 | 1 | 2 | 1 | 2 | 450 | 0.2 | 0.9 | 2780.859 | 46.348 |
| 5 | 1 | 2 | 2 | 2 | 450 | 0.315 | 1.42 | 4176.76 | 69.613 |
| 6 | 1 | 2 | 3 | 2 | 450 | 0.4 | 1.74 | 5040.271 | 84.005 |
| 7 | 1 | 3 | 1 | 2 | 710 | 0.2 | 0.86 | 4130.586 | 68.843 |
| 8 | 1 | 3 | 2 | 2 | 710 | 0.315 | 1.14 | 6592.809 | 109.88 |
| 9 | 1 | 3 | 3 | 2 | 710 | 0.4 | 1.2 | 7948.858 | 132.481 |
| 10 | 2 | 1 | 1 | 3 | 180 | 0.2 | 2.62 | 1125.464 | 18.758 |
| 11 | 2 | 1 | 2 | 3 | 180 | 0.315 | 5.38 | 1678.186 | 27.97 |
| 12 | 2 | 1 | 3 | 3 | 180 | 0.4 | 6.34 | 2013.394 | 33.557 |
| 13 | 2 | 2 | 1 | 3 | 450 | 0.2 | 2.32 | 2804.612 | 46.744 |
| 14 | 2 | 2 | 2 | 3 | 450 | 0.315 | 3.58 | 4184.776 | 69.746 |
| 15 | 2 | 2 | 3 | 3 | 450 | 0.4 | 6.24 | 5044.795 | 84.08 |
| 16 | 2 | 3 | 1 | 3 | 710 | 0.2 | 1.92 | 4429.516 | 73.825 |
| 17 | 2 | 3 | 2 | 3 | 710 | 0.315 | 3.44 | 6591.404 | 109.857 |
| 18 | 2 | 3 | 3 | 3 | 710 | 0.4 | 5.18 | 7929.227 | 132.154 |
| 19 | 3 | 1 | 1 | 4 | 180 | 0.2 | 2.04 | 1130.441 | 18.841 |
| 20 | 3 | 1 | 2 | 4 | 180 | 0.315 | 4.8 | 1688.163 | 28.136 |
| 21 | 3 | 1 | 3 | 4 | 180 | 0.4 | 6.06 | 2029.229 | 33.82 |
| 22 | 3 | 2 | 1 | 4 | 450 | 0.2 | 2.24 | 2824.407 | 47.073 |
| 23 | 3 | 2 | 2 | 4 | 450 | 0.315 | 3.84 | 4213.281 | 70.221 |
| 24 | 3 | 2 | 3 | 4 | 450 | 0.4 | 4.66 | 5068.549 | 84.476 |
| 25 | 3 | 3 | 1 | 4 | 710 | 0.2 | 2.7 | 4460.748 | 74.346 |
| 26 | 3 | 3 | 2 | 4 | 710 | 0.315 | 3.76 | 6649.026 | 110.817 |
| 27 | 3 | 3 | 3 | 4 | 710 | 0.4 | 4.28 | 8007.751 | 133.463 |

The control factors and their levels are illustrated in Table 2. The dependent variable is surface roughness. Table 3 shows standard L27 (33) orthogonal array designed by Taguchi with experimental results.

The Table 3 includes coding values of control factors, real values of cutting parameters and the results of the measured values of the surface roughness and calculated values. The different units used here are: speed- rpm, feed - mm/ rev, depth of cut -mm and surface roughness Ra - µm. Design – MINTAB software was used for Taguchi's method and for analysis of variance (ANOVA). The obtained results are analyzed using Minitab software and all the values are shown in the Table 4,5 and 6 and figures 4,5,6.

**Table: 4.** Ranking of cutting parameters

| **Level** | **1** | **2** | **3** | **Rank** |
|---|---|---|---|---|
| **Rake Angle** | $2^0$ | $3^0$ | $4^0$ | 3 |
| **Speed** | 180 | 450 | 710 | 1 |
| **Feed** | 0.2 | 0.315 | 0.4 | 2 |

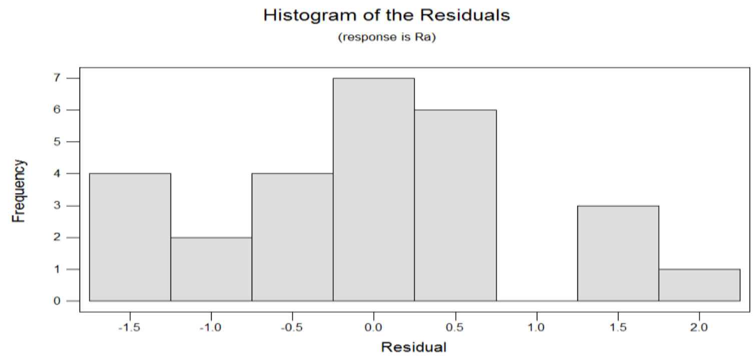


**Fig: 1.** Residual Histogram for Ra

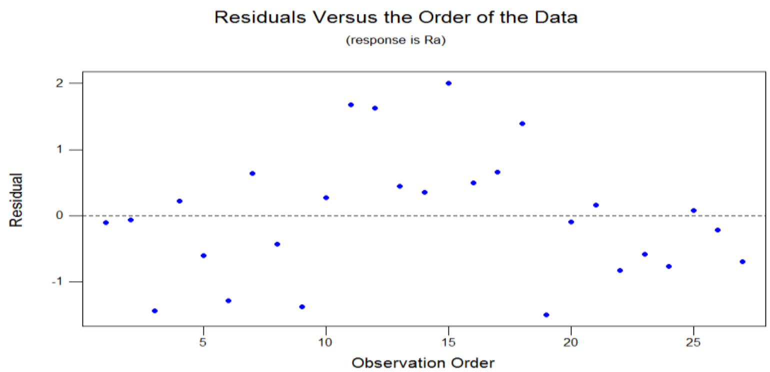


**Fig: 2.** Residuals vs Order for Ra

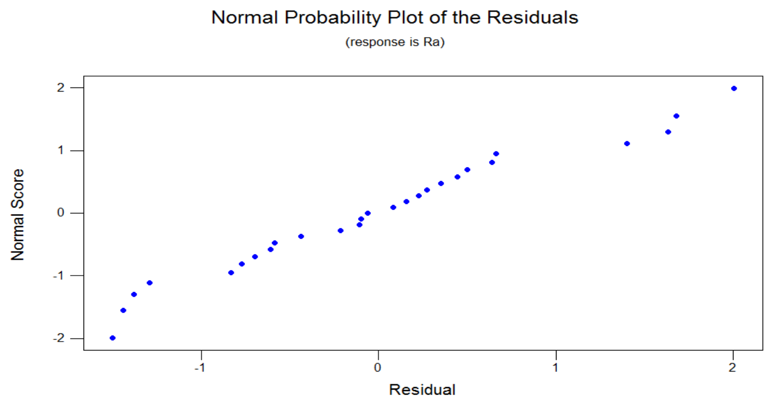


**Fig: 3.** Normplot of Residuals for Ra

**Table: 5.** S/N Ratio for Smaller the Better

| Rake Angles | Speed | Feed | Ra | MRR | SNRA1 | STDE1 | MEAN1 | CV1 |
|---|---|---|---|---|---|---|---|---|
| **2** | 180 | 0.2 | 1.04 | 1113.93 | -57.9269 | 786.93 | 557.49 | 1.41158 |
| **2** | 450 | 0.315 | 1.42 | 4176.76 | -69.4065 | 2952.41 | 2089.09 | 1.41325 |
| **2** | 710 | 0.4 | 1.2 | 7948.86 | -74.9958 | 5619.84 | 3975.03 | 1.41379 |
| **3** | 180 | 0.315 | 5.38 | 1678.19 | -61.4866 | 1182.86 | 841.79 | 1.40518 |
| **3** | 450 | 0.4 | 6.24 | 5044.8 | -71.0466 | 3562.8 | 2525.52 | 1.41072 |
| **3** | 710 | 0.2 | 1.92 | 4429.52 | -69.9168 | 3130.79 | 2215.72 | 1.41299 |
| **4** | 180 | 0.4 | 6.06 | 2029.23 | -63.1364 | 1430.6 | 1017.65 | 1.40579 |
| **4** | 450 | 0.2 | 2.24 | 2824.41 | -66.0083 | 1995.58 | 1413.32 | 1.41197 |
| **4** | 710 | 0.315 | 3.76 | 6649.03 | -73.4449 | 4698.92 | 3326.4 | 1.41262 |

**Table: 6.** S/N Ratio for Larger the Better

| Rake Angles | Speed | Feed | Ra | MRR | SNRA2 | STDE2 | MEAN2 | CV2 |
|---|---|---|---|---|---|---|---|---|
| **2** | 180 | 0.2 | 1.04 | 1113.93 | 3.351 | 786.93 | 557.49 | 1.41158 |
| **2** | 450 | 0.315 | 1.42 | 4176.76 | 6.0561 | 2952.41 | 2089.09 | 1.41325 |
| **2** | 710 | 0.4 | 1.2 | 7948.86 | 4.5939 | 5619.84 | 3975.03 | 1.41379 |
| **3** | 180 | 0.315 | 5.38 | 1678.19 | 17.6259 | 1182.86 | 841.79 | 1.40518 |
| **3** | 450 | 0.4 | 6.24 | 5044.8 | 18.914 | 3562.8 | 2525.52 | 1.41072 |
| **3** | 710 | 0.2 | 1.92 | 4429.52 | 8.6763 | 3130.79 | 2215.72 | 1.41299 |
| **4** | 180 | 0.4 | 6.06 | 2029.23 | 18.6597 | 1430.6 | 1017.65 | 1.40579 |
| **4** | 450 | 0.2 | 2.24 | 2824.41 | 10.0153 | 1995.58 | 1413.32 | 1.41197 |
| **4** | 710 | 0.315 | 3.76 | 6649.03 | 14.5141 | 4698.92 | 3326.4 | 1.41262 |

## 2.1 Main effect plots analysis for Ra

The analysis is made with the help of software package MINITAB. The main effect plot for Ra and MRR are shown in following figures .They show the variation of individual response with three parameters i.e. rake angle, speed, and feed separately. In the plot x-axis represents the value of each process parameter and y-axis is response value. Horizontal line indicates the mean of the response. The main effect plots are used to determine the optimal design conditions to obtain the optimal surface finish. According to this main effect plot, the optimal conditions for minimum surface roughness are rake angle at level 2 ($3^0$), speed at level 1 (180 RPM) and feed rate at level 1 (0.2 mm/rev) at constant depth of cut (0.2mm). The main effect plot for S/N ratios of the Surface roughness for data means is shown in Fig 4, 5 and 6. Signal-to-Noise ratio of common interest for optimization for surface roughness is smaller the better.

The diagnostic checking has been performed through residual analysis for the developed model. The residual plots for surface roughness are shown in Fig 1,2and 3. These are generally fall on a straight line implying that errors are distributed normally.

From Figures it can be concluded that all the values are within the control range, indicating that there is no obvious pattern and unusual structure and also the residual analysis does not indicate any model inadequacy. Hence these values yield better results in future predictions.

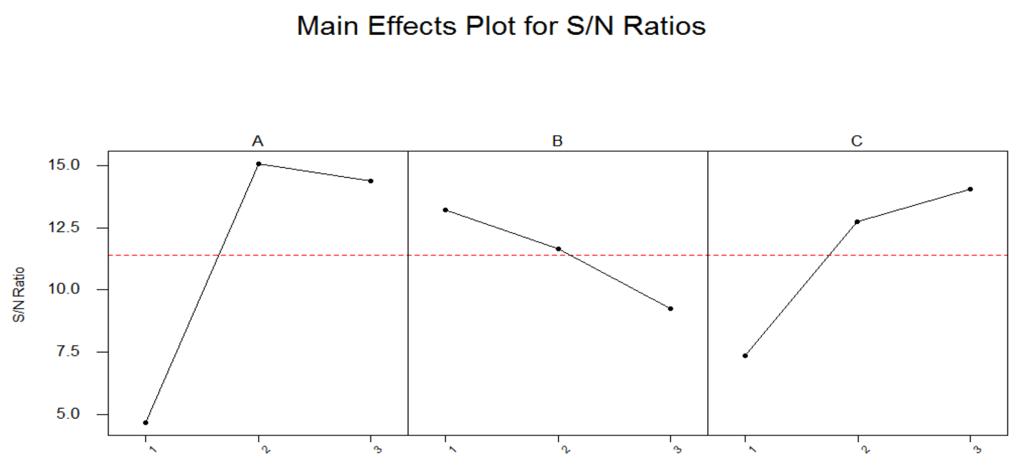


**Fig: 7.** Main Effects for S/N Ratios: MRR

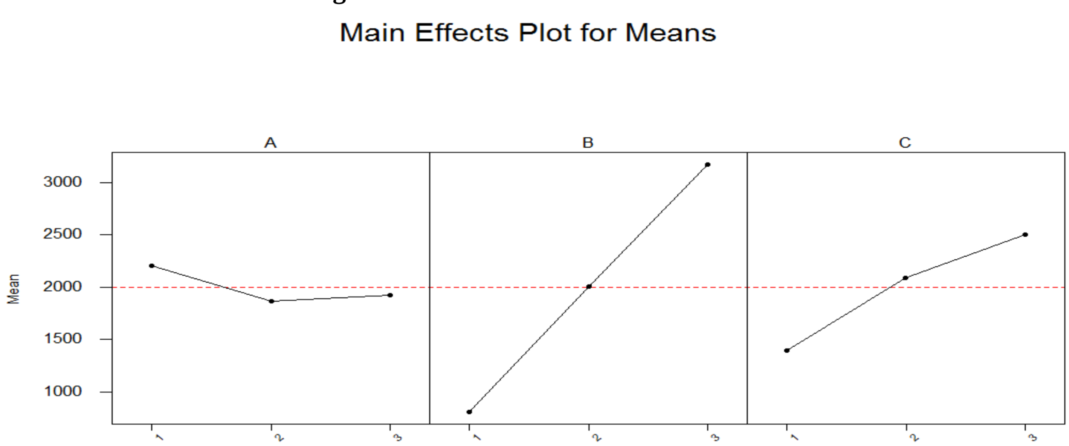


**Fig: 8.** Main Effects for Means: MRR

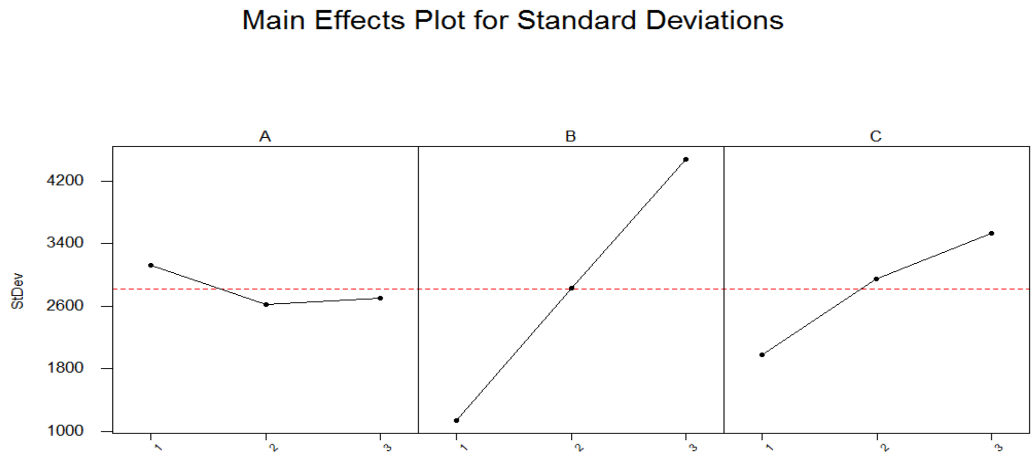


**Fig: 9.** Main Effects for St Devs: MRR

**Table: 7.** Response Table for Signal to Noise Ratios for Ra and MRR

| Response Table for Signal to Noise Ratios for Ra | | | | Response Table for Signal to Noise Ratios for MRR | | | |
|---|---|---|---|---|---|---|---|
| **Smaller is better** | | | | **Larger is better** | | | |
| Level | A | B | C | Level | A | B | C |
| 1 | -67.4430 | -60.8499 | -64.6173 | 1 | 4.6670 | 13.2122 | 7.3475 |
| 2 | -67.4833 | -68.8204 | -68.1126 | 2 | 15.0721 | 11.6618 | 12.7320 |
| 3 | -67.5298 | -72.7858 | -69.7262 | 3 | 14.3963 | 9.2614 | 14.0559 |
| Delta | 0.0868 | 11.9359 | 5.1089 | Delta | 10.4051 | 3.9508 | 6.7084 |
| Rank | 3 | 1 | 2 | Rank | 1 | 3 | 2 |

## 3. Conclusions

This work presented an experimentation approach to study the impact of machining parameters on surface roughness. Strong interactions were observed among the turning parameters. Most significant interactions were found between rake angle, feed and cutting speeds. A Systematic approach was provided to design and analyze the experiments, and to utilize the data obtained to the maximum extend.

The following are conclusions drawn based on the experimental investigation conducted at three levels by employing Taguchi technique to determine the optimal level of process parameters.

- From the data collection it has been observed that the finish gets poor as the feed increases, thus the average surface roughness value increases with increase in feed.
- The optimal combination process parameters for minimum surface roughness are obtained at 30, 180 rpm, and 0.2 mm/rev with constant depth of cut 0.2 mm.
- The optimal combination process parameters for maximum material removal are obtained at 20, 710 rpm, and 0.4 mm/rev with constant depth of cut 0.2 mm.
- Taguchi gives systematic simple approach and efficient method for the optimum operating conditions.

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