SURFACE ROUGHNESS ANALYSIS WHILE MACHINING AISI 1040 STEPPED STEEL BAR USING TAGUCHI DESIGN OF EXPERIMENTS

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Abstract : The main objective of today's manufacturing industries is to produce low cost, high quality products in short time. The selection of optimal cutting parameters is a very important issue for every machining process in order to enhance the quality of machining products and reduce the machining costs. Surface inspection is carried out by manually inspecting the machined surfaces.This work focuses on the study of surface roughness and Tool tip temperatures and while machining AISI 1040 stepped steel bar for various combinations of machining parameters like feed, depth of cut and speed based on Taguchi philosophy using TiN-Al2O3-TiCN-TiN Carbide inserts using dry conditions.The Surface Roughness tester and Thermocouple are used to measure the surface roughness and temperatures respectively and are used to analyze the effect on variation in machining parameters on the surface roughness in turning operation. Taguchi Design method carried out for experimental design (DOE using L16 Orthogonal Array) and the analysis of contribution of process parameters based experimental results is analyzed using Regression Analysis in MINITAB software. ANOVA technique has been applied to get the interaction plots of surface roughness.

IndexTerms - **Surface Roughness, Taguchi Method, L16 orthogonal Array, Regression Analysis, ANOVA.**

I. INTRODUCTION

Every manufacturing industry aims at producing a large number of products within relatively lesser time. But it is felt that reduction in manufacturing time may cause severe quality loss. In order to embrace these two conflicting criteria is necessary to check quality level of the product. In machining operation, the quality of surface finish was an important requirement for many turned work pieces. Thus the choice of optimized cutting parameters was very important for controlling the required surface quality. The focus of this study was to find a correlation between surface roughness and cutting speed, feed and depth of cut based on Taguchi's philosophy.

1.1 TURNING OPERATION: Turning is a machining process to produce parts round in shape by a single point tool on lathes. The tool is fed either linear in the direction parallel or perpendicular to the axis of rotation of the workpiece, or along a specified path to produce complex rotational shapes. The primary motion of cutting in turning is the rotation of the workpiece, and the secondary motion of cutting is the feed motion. The RPM depends on the cutting speed and the diameter of the part. The RPM setting will change with the diameter of the part. As the diameter of the part gets smaller, the RPM must increase to maintain the recommend surface footage. Nearly all turning process use single point cutting tools, this is, tool that cut with only a single edge in contact with the work. Most turning is done with coated index able carbide inserts, but the tool material may also be high speed steel, brazed carbide, ceramic, cubic boron nitride or polycrystalline diamond. 75% of turning operations use just a few basic tool geometries. When turning with inserts, much of the geometry is built into to the tool holder itself rather that actual insert. In turning, chip breaking is critical to efficient work processing and good finishing qualities. Proper chip breaking results from balancing the depth of cut and the geometry of the tool. The first type, shaped like numerals "6" or "9", represents the ideal chips. The other types indicate the need for speed and feed adjustments, or selection of a different chip breaker design.

1.2 CNC LATHE:

Nowadays, more and more Computer Numerical Controlled (CNC) machines are being used in every kind of manufacturing process. In a CNC machine, functions like program storage, tool offset and tool compensation program-editing capability, various degree of computation, and the ability to send and receive data from a variety of sources, including remote locations can be easily realized through on board computer. The computer can store multiple part programs, recalling them as needed for different parts. CNC is useful to manufacture complex curved geometries in 2D or 3D which was extremely expensive by mechanical means (which usually would require complex jigs to control the cutter motions) . Other advantages include Machining components with high Repeatability and Precision , Unmanned machining operations and to improve production planning and to increase productivity.

Fig. 1.1. CNC Lathe Machine used for machining.

2.1 DESIGN OF EXPERIMENTS

Design of experiments (DOE) or experimental design is the design of any information gathering exercises where variation is present, whether under the full control of the experimenter or not. However, in statistics these terms are usually used for controlled experiments. Former planned experimentation is often used in evaluating physical objects, chemical formulations, structures, components and materials. In the design experiments, the experimenter is often inserted in the effect of some process or intervention (the treatment) on some objects(the experimental units) which may be people, parts of people, groups of people, plants, animals etc. Design of experiments is thus a discipline that has very broad application across all the natural and social sciences and engineering.

The major design of experiments terms generally include:

- Blocking: When randomizing a factor it is impossible or too costly, blocking lets you restrict randomization by carrying out all of the trials with one setting of the factor and then all the trials with the other setting.
- Randomization: Refers to the order in which the trials of an experiment are performed. A randomized sequence helps to eliminated effects of unknown or uncontrolled variables.
- Replication: This is the process of repetition of a complete experimental treatment including the setup.
- Reflection: A reflection is a new set of combinations that are run at the opposite levels of the original set.

2.2 TAGUCHI METHOD

One method presented in this study is an experimental design process called the Taguchi design method. Taguchi design, developed by Dr. Genichi Taguchi, is a set of methodologies by which the inherent variability of materials and manufacturing processes has been taken into account at the design stage.

Three steps procedure for experimental design:

1. Find the total degree of freedom (TOF)
2. Select a standard orthogonal array using the following two rules:
    - The number of runs in the orthogonal design $\geqslant$ Total DOF
    - The selected orthogonal array should be able to accommodate the factor level combinations in the experiment.
3. Assign factors to appropriate columns

Taguchi’s approach to parameter design provides the design engineer with a systematic and efficient method for determining near optimum design parameters for performance and cost (Kackar, 1985; Phadke, 1989; Taguchi 1986). The objective is to select the best combination of control parameters so that the product or process is most robust with respect to noise factors, The Taguchi method utilizes orthogonal arrays from design of experiments theory to study a large number of variables with a small number of experiments. Using orthogonal arrays significantly reduces the number of experimental configurations to be studied. Furthermore, the conclusion drawn from mall scale experiments are valid over the entire experimental region spanned by the control factors and their settings.

For the vast majority of factorial experiments, each factor has only two levels. For example, with two factors each taking two levels, a factorial experiment would have four treatment combinations in total, and is usually called a 2x2 factorial design. If there are n factors at 2 levels, a full factorial design has 2^n runs.

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2.3 PROCESS PARAMETERS AND THEIR LEVELS:

Factors	Level-1	Level-2	Level-3	Level-4
Cutting Speed (rpm)	360	560	900	1250
Feed (mm/rev)	0.15	0.17	0.19	0.20
Depth of cut (mm)	0.25	0.5	0.75	1.0

Number of Factors	Number of Runs
2	4
3	8
4	16
5	32
6	64

Table 2.1. Process Parameters and their levels

3.1 Material Specifications

EN8 STEEL:- EN8 is also known as 080M40 and is an unalloyed medium carbon steel. EN8 is a medium strength steel, good tensile strength. This type of steel is generally suitable for shafts, stressed pins, studs, keys etc. EN8 steel is supplied or available as round/turned, round hot rolled, hexagon, flats and plates

Mechanical Properties of EN8 Steel:

Heat Treatment	Condition Tos/ SQ. Inch	Tensile Strength	Yield Stress RE MPA	RE 0,2 MPA	Hardness HB
Normalize	35	550	-	16	152/207
Q	40/50	625/775	355	16	179/229
R	45/55	700/850	450	16	201/255

EN8 - 080M40 Black (As rolled or forged) 40 Ton Tensile Black Axle Steel (Carbon Steel)
Equivalents: BS970 Part 1 1983, 080M40 BS970 of 1955 EN8 German W. Stoff No. 1.1186 | American AISI 1038
Chemical: Composition % Carbon = 0.36 - 0.44 Silicon = 0.10 - 0.40 Manganese = 0.60 - 1.00 Sulphur = 0.050 max Phosphorus = 0.050 max

3.2 Cutting Tool

TiCN-Al_2O_3-TiN coating on a substrate features excellent resistance to both mechanical and thermal shock. This gives excellent adhesion with high wear resistance to crater wear and plastic deformation at high temperatures. Also reduces friction and hence the formation of built up edges.

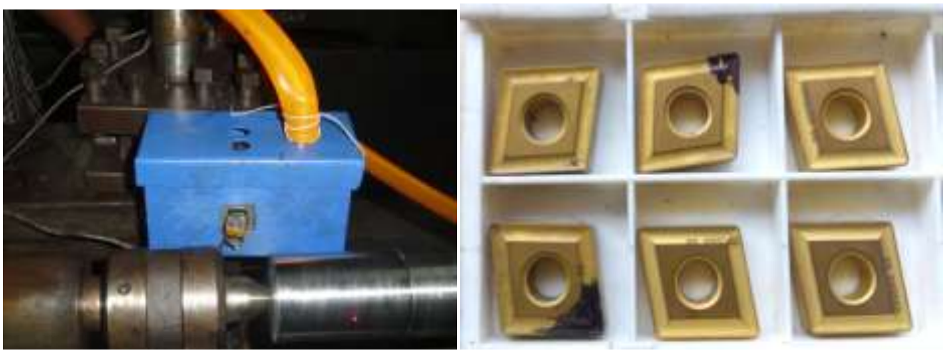

Figure 3.1 **Cutting Tool (CARBIDE INSERT)**

3.3 Measurement of Cutting Temperatures

Cutting Temperatures indicate the amount of heat generated during machining. To assay the effectiveness of the cutting fluid as coolant, cutting temperatures are measured. Embedded thermocouple is used to measure the temperature if the cutting tool insert at a nodal point. Digital temperature indicator is used for recoding and displaying the temperature of the hot junction of thermocouple.

Designation:	K type, Shielded Thermocouple
Element outside Diameter:	2 mm
Element Length:	120 mm
Element Type:	Duplex
Sheath Material:	Recrystallized Alumina
Temperature Range:	-250^{0}C to 1260^{0}C

Machining tests are carried out under constant cutting conditions to assess the performance of fluids in machining. Tool temperature is measured at a nodal point. Heat transfer coefficients are calculated for the fluids with different fluids of varying nano - particle concentration.

4.1SURFACE ROUGHNESS AND ITS IMPORTANCE

Roughness plays an important role in determining how a real object will interact with its environment. Rough surfaces usually wear more quickly and have higher friction coefficients than smooth surface. Roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion. On the other hand, roughness may promote adhesion. A roughness value can either be calculated on profile (line) or on a surface (area). The profile roughness parameter (Ra, Rq,...) are more common. The area roughness parameters (Sa, Sq...) give more significant valuesThe surface tester used in the experiment is SJ 301. The surf test SJ 301 is a stylus type surface roughness measuring instrument developed for shop floor use. The measurement results are displayed on the touch panel, and output to the built - in printer.

Specifications of Detector:

Detection Method:	Differential Inductance Method
Measuring range:	350 gm (-200 to +150 pm)
Stylus Material:	Diamond
Tip Radius:	5 pm
Measuring Force:	4 mN
Radius of the Skid Curvature:	40 mm

4.2 EXPERIMENTATION METHODOLOGY

Procedure:

1. Insert a new Carbide tool insert
2. Start machining of the workpiece with the test conditions that were obtained from Taguchi Design of experiments
3. During the process of machining the Temperatures through thermocouple were captured.
4. Once the machining for each test condition is completed surface roughness was tested with MITUTOYO tester and Material Removal Rate is calculated
5. Analysis was done for Surface roughness , Temperatures and Material Removal Rate.

5.1 APPLICATION OF MINITAB SOFTWARE

MINITAB provides a wide range of basic and advanced statistics, including exploratory data analysis, basic statistics, regression, analysis of variance (ANOVA), multivariate analysis, time series, cross-tabulations, simulations and distributions. It also has facilities to produce a comprehensive array of graphs.

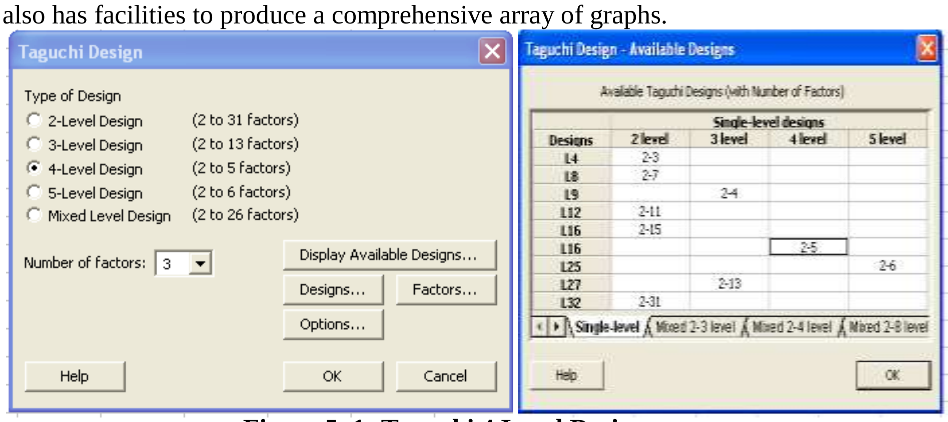

Figure 5. 1: Taguchi 4 Level Design

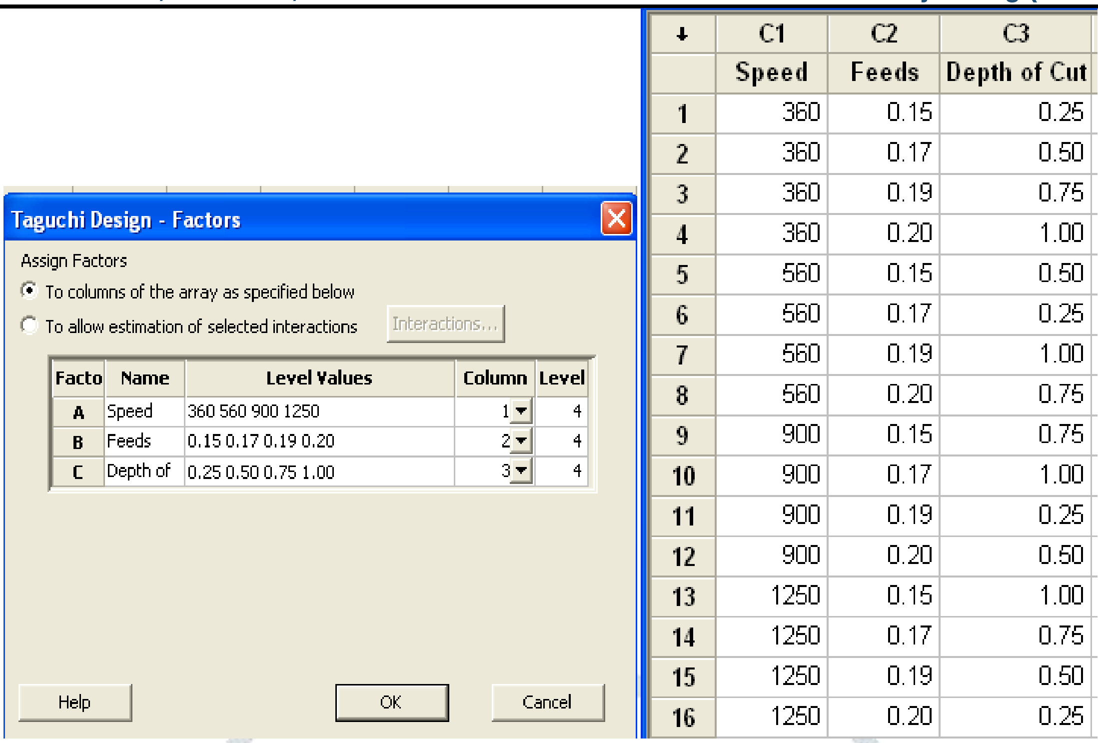

Figure 5.2: Taguchi Design Factors

5.2 REGRESSION ANALYSIS

Regression analysis is statistical technique for estimating the relationships among variables. It includes many techniques for modeling and analyzing several variables when the focus is on the relationship between a dependent variable and one or more independent variables. More specifically, regression analysis helps one understand how the typical value of the dependent variable changes when any one of the independent variables are varied, while the other independent variables are held fixed

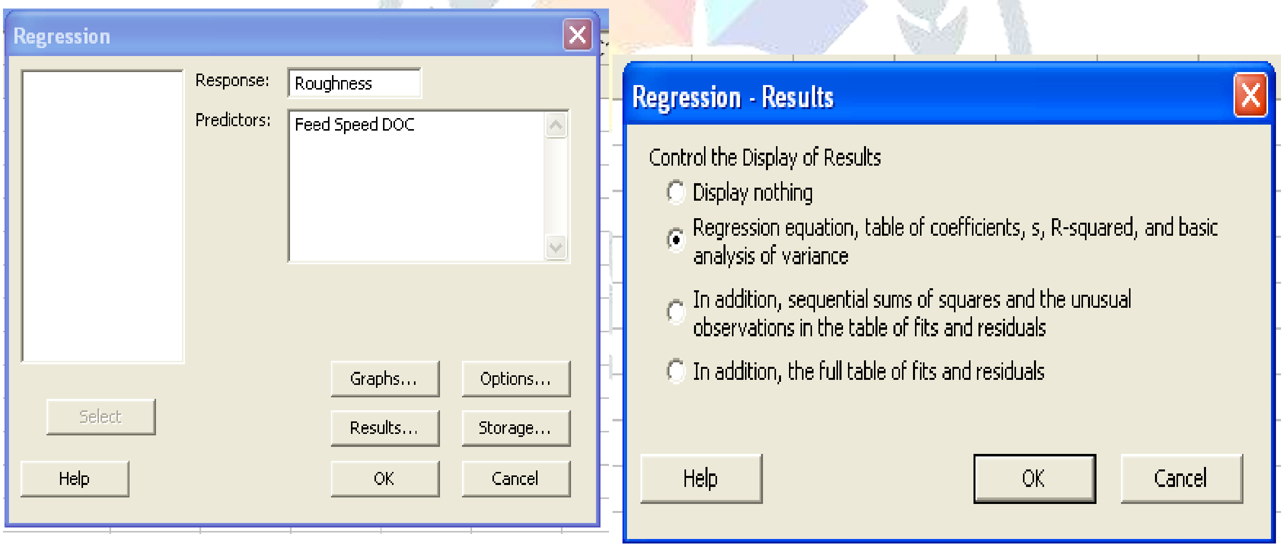

Figure 5. 3: Regression Analysis using MINITAB

6.1 EXPERIMENTAL RECORDINGS AND ANALYSIS

Workpiece	Average Surface Roughness (microns)	Feed (mm/ rev)	Diameter of workpiece	Spindle Speed (RPM)	Depth of cut (mm)	ToolTip Temperature (^{0}C)
Run 1- 1	2.93		60	360	0.25	31.5
Run 1- 2	1.77		59	560	0.5	42
Run 1- 3	1.12		57	900	0.75	27.1
Run 1- 4	0.94	0.15	54	1250	1.0	17.9
Run 2- 1	1.97		60	360	0.5	36
Run 2- 2	1.7		59.5	560	0.25	55
Run 2- 3	1.64		56	900	1.0	28.5
Run 2- 4	1.57	0.17	55.5	1250	0.75	21.5
Run 3- 1	2.97		60	360	0.75	41
Run 3- 2	1.9		58	560	1.0	33
Run 3- 3	1.62		59	900	0.25	35.9
Run 3- 4	1.57	0.19	57	1250	0.5	22.4
Run 4- 1	2.79		60	360	1.0	45
Run 4- 2	1.96		58.5	560	0.75	39
Run 4- 3	1.85		58	900	0.5	35.3
Run 4- 4	1.8	0.2	58.5	1250	0.25	24.7

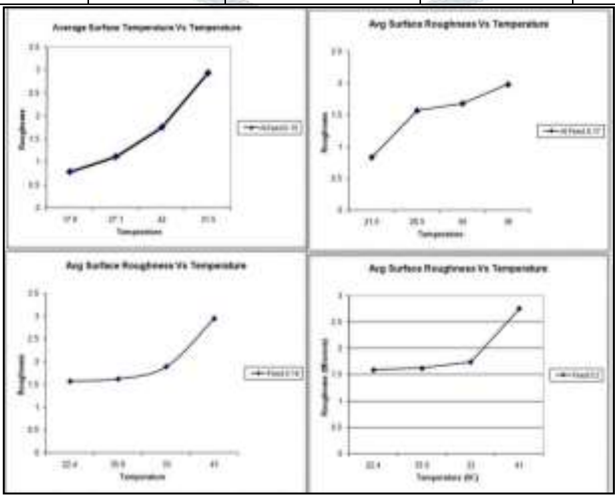

Figure 6.1: Plot of Surface Roughness Vs Temperature

From the graph,

- At feed 0.15 as the temperature increases the surface roughness is increasing rapidly.
- At feed 0.17 as the temperature increases the surface roughness is gradually increasing.

- At feed 019 as the temperature increases the surface roughness did not show any variation till third point and then increased suddenly.

Finally, at feed 0.20 as the temperature increases the surface roughness increases gradually till the third point and then increases suddenly

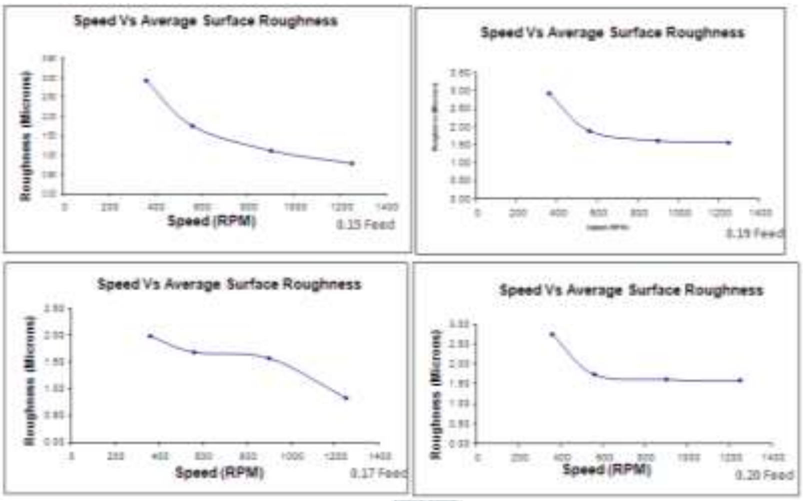

Figure 6.2: Plot of Surface Roughness Vs Speed

- At 0.15 feed, as the speed increases the average surface roughness of the workpiece decreases rapidly in all the runs.
- At 0.17 feed, as the speed increases the average surface roughness of the workpiece decreases gradually in all the four runs.
- At 0.19 feed, as the speed increases the average surface roughness of the workpiece decreases rapidly between third and fourth run.
- At 0.20 feed, as the speed increases the average surface roughness of the workpiece increases rapidly between first and second run. The roughness remains constant during second, third and fourth runs.

6.2 **Regression Results**

Regression Analysis: Roughness versus Feed, Speed, DOC

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The regression equation is
Roughness = 2.78 + 0.134 Feed - 0.466 Speed - 0.0697 DOC

Predictor       Coef  SE Coef      T      P
Constant      2.7763   0.3423   8.11  0.000
Feed         0.13375  0.07654   1.75  0.106
Speed       -0.46575  0.07654  -6.09  0.000
DOC         -0.06975  0.07654  -0.91  0.380

S = 0.342284   R-Sq = 77.3%   R-Sq(adj) = 71.7%

Analysis of Variance

Source          DF      SS      MS      F      P
Regression       3  4.7935  1.5978  13.64  0.000
Residual Error  12  1.4059  0.1172
Total           15  6.1994
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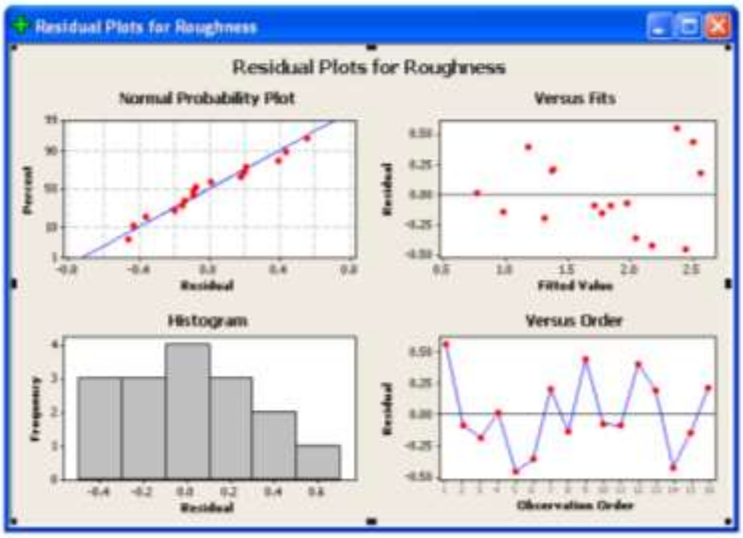

Figure 6.3: **Regression Analysis: Roughness versus Feed, Speed, DOC**

Predictor	Coef	SE	T	P
Constant	2.7763	0.3423	8.11	0
Feed	0.13375	0.07654	1.75	0.106
Speed	-0.4658	0.07654	-6.09	0
DOC	-0.0698	0.07654	-0.91	0.38

The Regression equation is: Roughness = 2.78 + (0.34 * Feed) - (0.466 * Speed) - (030697 * DOC)

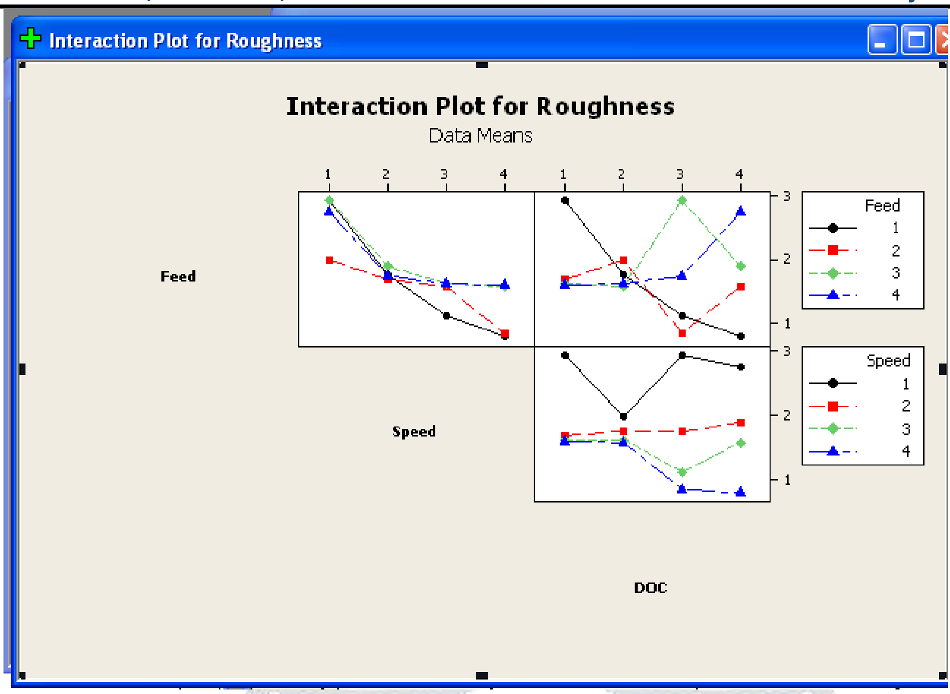

Figure6.4: Interactions Plots for Roughness

At Confidence level 95% ,

Source	DF	Seq SS	Adj MS	F	P	$F_{critical}$	Remark
Regression	3	4.7935	1.5798	13.64	0	3.49	Significant
Residual Error	15	1.4059	0.1172				
Total	18	6.1994					

Table 6.1: Regression Table

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