Response Surface Optimization Of Machining Parameters In Turning Of AISI 316 Chromium-Nickel Stainless Steel

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ABSTRACT

Machining operations are inevitable in fabrication of the product to the required dimension and shape. Turning operation is one of the most accepted machining courses in the metal cutting process. As the economies of the operations depend on the input and output parameters, in order to obtain the reasonable product, one has to locate the set of input machining parameters with reference to the resultant parameters. This requires the optimization of cutting parameters as the key component in preparation of machining processes.This investigation is focused on obtaining the optimum process parameters to get minimum surface roughness, tool temperature and maximum metal removal rate in Turning operation. Experimentation was done using Taguchi's L9 orthogonal array. Response Surface Methodology (RSM) was adopted to find the optimum machining parameters. The factors of the experimental analysis consist of Spindle Speed, Feed Rate, Depth of Cut while the responses of the model are Metal removal rate, Surface roughness and Tool Temperature.Analysis of Variance (ANOVA) is done to determine the contribution percentage of each input factors that affects the output parameter in one way or the other. The tests are performed on AISI 316 grade of Stainless-Steel using tungsten carbide tipped tool as cutting tool.

Keywords: AISI, ANOVA, RSM, Taguchi, tipped tool, Turning operation.

1. INTRODUCTION

The most effective and commonly used form of metal removal in any engineering or manufacturing industries is Metal cutting. Turning operation is a type of metal removal processes which removes excess material using a cutting tool of hardness greater than the work piece. The primary objective of any metal removal operation is to produce products with lower power consumption and high metal removal rate. Optimization of machining parametersplays very important role in achieving desired goal. The process of optimization usually involves the optimal selection of control factors namelyspindle speed, feed rate and depth of cut. Optimization is carried out independently for every operation on every machine. All manufacturing industries work with different varieties of products and hence use different variation of machines, hence optimization of each such machines with its work material are necessary and the results of optimized parameters do vary from one another in many ways depending on working conditions. Thus, optimization provides significant efficient result leading to high production with lower power consumption and improved product quality. Significant and improved process efficiency can only be achieved by optimization of process parameter. Machining is defined as a metal removal process in which the excess metal from the work piece is removed in the form of chips by means of single or multiple point cutting tool of hardness greater than the work piece.

D. S. Sai Ravi Kiran, Balla Srinivasa Prasad [1] has done experimental investigation on the influence of drilling parameters on circularity error, tool tip temperature and flank wear while drilling of Ti–6Al–4V alloy specimens with dissimilar cutting tool materials under dry machining conditions.They concluded that, Drill bit material influences (DM = 73.67%) more, followed by rotational speed (N = 16.87%) and feed rate (f = 7.86%). Akhil C S, Ananthavishnu M H, Akhil C K, Afeez P M, Akhilesh R, Rahul Rajan [2] conducted various experiments to measure the cutting temperature during machining and concluded that if the depth of cut increases, the section of chip increases and friction of chip-tool increases which leads to an increase in temperature. S B Chikalthankar, R B Kakade, V M Nandedkar [3] conducted an experiment which evaluates the tool tip temperature in Turning of OHNS with carbide cutting tool.It has been observed that the depth of cut was the most influencing parameter followed by spindle speed and feed. Naveen Kumar, Sumit Mishra, Sidharth Mishra [4] has done analysis on metal removal rate in turning of AISI 304 stainless steel.ANOVA analysis is done to find out the effect of each cutting parameters upon MRR and it is observed from ANOVA response table that RPM contributes to 85.05% and DOC 8.94% towards MRR upon constant feed of 30 teeth per inch. Raman Kumar, Gaurav Soni and Saurabh Chhabra [5] had done analysis to study the effects of input parameters such as speed, feed, depth of cut and nose radius on output parameter such as material removal, surface roughness and time.The result shows that speed 1500rpm, feed, D.O.C 1mm and nose radius at 1.2 is the appropriate best input parameters setting.Neeraj, Sukhdeep S. Dhami [6] performed studies on process parameters such as spindle speed, feed, depth of cut, environment, nose radius, and the impact on surface roughness, material removal rate, power consumption, tool wear rate, and thrust force. This work consists of an analysis of the work carried out by the researchers in the field of filming process parameters, to Examine the impact of speed, cutting speed (feed), and depth of cut in a computer numeric control machine.

This study will provide insight into current trends research in the area of Taguchi, Grey Relational Analysis, Response Surface Method, ANOVA & CNC Turning. Ashvin, J. Makadia, J.I. Nanavati [7] studied the effect of the main turning parameters such as feed rate, tool nose radius, cutting speed and depth of cut on the surface roughness of AISI 410 steel.The result shows that the feed rate is the main influencing factor on the roughness, followed by the tool nose radius and cutting speed, roughness has been investigated by using Response Surface Methodology (RSM). Kali Dass, S.R. Chauhan [8] studied the performance of polycrystalline diamond (PCD) cutting insert during turning of titanium (Grade-5) alloy using response surface methodology (RSM). The result shows that the surface roughness increases with increase in the cutting speed and the feed rate decreases with decrease in approach angle and depth of cut. The tangential force increases with increase in approach angle and depth of cut, and decreases with decrease in cutting speed and feed rate. Sahoo P [9] conducted an experimental study of roughness characteristics of surface profile generated in CNC turning of AISI 1040 mild steel and optimization of machining parameters based on genetic algorithm. It is seen that the surface roughness parameters decrease with increase in depth of cut and spindle speed but increase with increase in feed rate.Korat and Agarwal [10] used Taguchi techniques to optimizethe effects of cutting parameters on surface finish and MRRof AISI4340 in CNC turning.

Theorthogonal array, signal to noise ratio and ANOVA were employed to study the performancecharacteristics in turning operation. This research concludedthat it is possible to increase machine usage and reduce production cost in an automated manufacturing environment.Sanchit Kumar Kharea, Sanjay Agarwal [11]has done research on cryogenic turning process involves the modelling and optimization of the process parameters (cutting speed, feed rate, depth of cut, rake angle) affecting the machining performance and value oriented sustainable manufacturing. An orthogonal array (L9), the signal-to-noise (S/N) ratio was employed to the study the surface roughness in the turning of AISI 4340 steel under cryogenic condition. It was observed that cutting speed and depth of cut was the most influential factors on the surface roughness.Ahilan Chandrakasan, Somasundaram Kumanan, N. Sivakumaran [12]used Grey based fuzzy logic approach in optimization of CNC turning process with multiple performance characteristics. This approach integrates both grey relational analysis and fuzzylogic for optimizing the complicated multiple performance characteristics. Optimum level of parameters has been identified based on grey-fuzzy reasoning grade.

In this study, CNC turning parameters namely cutting speed, feed rate, depth of cut and nose radius are optimized with consideration of performance characteristics such as surface roughness and power consumption. The significant contributions of parameters are estimated by using Analysis of Variance (ANOVA).J.Chandrashekar, Mahipal Manda, D. Vijay Kumar [13]has given the best condition for cutting speed factor is level 3 (96.6 m/min) (1025 rpm), for feed is level 2 (150 mm/rev), for depth of cut is level 2 (0.8mm), straight cutting oil in cutting fluids in level 3 for work piece material AISI stainless steel. It was clear that the S/N ratio is larger at cutting fluid, straight cutting oil. Then we can say that the optimum cutting fluid is straight cutting oil. It means that the values we got by using straight cutting oil are optimum values. Neeraj Sharma, Karnal Renu Sharma [14] applied extended Taguchi method through a case study in straight turning of mild steel bar using HSS tool for the optimization of process parameters. It was found that the depth of cut is most significant, spindle speed is significant and feed rate is least significant factor effecting surface roughness.I. Ramu, P. Srinivas, K. Venkatesh[15] focused on optimization of turning parameters using the Taguchi technique to minimize surface roughness and maximize material removal rate. Turning operations are performed based on the orthogonal array with L9 for SS316. Grey relation grade is used to calculate the optimal condition for combined parameters.From the analysisof variance of the S/N ratios it was found that feed is the important factor effecting the surfaceroughness followed by speed and depth of cut.

2. MATERIAL AND DESIGN OF EXPERIMENTS

2.1 Workpiece

The work piece material used for experiments is **AISI 316 Stainless Steel** of 32 X 50 mm (fig 2.1). SS AISI 316 is used harsher environments.

Table 2.1: Chemical composition of AISI 316 SS

Fe	Cr	Ni	Mo	Mn	Si	N	C	P	S
68.5%	16.25%	11.%	2.5%	1%	0.5%	0.05%	0.04%	0.023%	0.015%

Table 2.2: Physical properties of AISI 316 SS

Density (g/cm3)	Elastic Modulus (G Pascal)	Mean Coeff. Of Thermal Expansion (µm/m/^{o}C)	Thermal Conductivity At 100^{o}C(W/m-K)	Specific Heat (J/kg-K)	Electrical Resistivity (nΩ.-m)
7.99	193	16.5	18.9	500	740

Figure 2.1. **Workpieces before machining**

2.2 Tool

- The tool used for machining is Tungsten Carbide tipped tool.

Figure 2.2.**Tungsten Carbide Tipped Tool**

2.3 Design of Experiments (DOE)

DOE helps you investigate the effects of input variables (factors) on an output variable (response) at the same time. These experiments consist of a series of runs, or tests, in which purposeful changes are made to the input variables. Data are collected at each run. You use DOE to identify the process conditions and product components that affect the quality and then determine the factor settings that optimize results. Minitab offers five types of designs: screening designs, factorial designs, response surface designs, mixture designs, and Taguchi designs (also called Taguchi robust designs).

2.3.1 Taguchi Method:

It is a method to design an experiment, as it creates the set of arrays with variable factors arranged in such a way that only significant variation is pointed out and rest of insignificant set of variables are neglected thus reducing the no. of experiments.

Table 2.3: Parameter setting

Level	Spindle Speed (RPM)	Feed Rate (mm/rev)	Depth of Cut (mm)
1	835	0.45	0.25
2	1330	0.75	0.50
3	2000	1	0.75

Table 2.4: Taguchi Design Summary

Taguchi Array	L9(3^3)
Factors	3
Runs	9

Table 2.5: L9(3^4) Array of influencing parametersand their levels

Expt. No	Spindle Speed (RPM)	Feed Rate (mm/rev)	Depth of Cut (mm)
1	835	0.45	0.25
2	835	0.75	0.50
3	835	1	0.75
4	1330	0.45	0.50
5	1330	0.75	0.75
6	1330	1	0.25
7	2000	0.45	0.75
8	2000	0.75	0.25
9	2000	1	0.50

3. EXPERIMTATION

3.1 Experimental Setup

A center lathe was used to carry out the machining. The insert was clamped in a holder and mounted on the tool post. The job was held rigidly by the chuck of the lathe. Centre drilling was done and the job was held at the other end by the tail stock and a skin pass was carried out. The setup was hence complete and the runs could be carried out from here.

Figure 3.1. **Centre Lathe with digital weighing machine**

3.2 Material Removal Rate (MRR) Calculation

In order to calculate metal removal rate first, the initial weight of each AISI 316 SS bar is taken from weighing device.Machining time is obtained from the formula.

Machining time (in seconds) = (Machining length/ (Spindle Speed*Feed Rate)) *60

After machining, final weight of each test bar is determined from weighing device.Finally, MRR is calculated by using formula,

MRR (cm3/sec) = (Initial Weight – Final Weight) / (Density * Machining time)

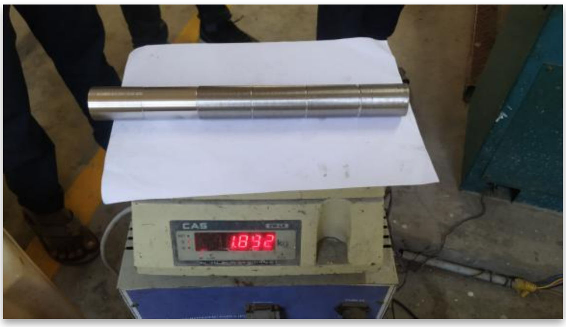

Figure 3.2.**Weighing workpiecebefore machining**

Figure 3.3.**Weighing workpiece after machining**

3.3 Surface Roughness Measurement

Surface Roughness of the machined surfaces is calculated using Talysurf Surface Roughness Tester.This tester measures surface roughness by using an electronic principle, this surface meter consistsof stylus and skid type instrument used for measuring the surface of the given product.In this instrument (fig 3.4), the stylus points out the profile of the surface and any deflections of a stylus is converted into electric current to identify the measurements of the object.

Figure 3.4. **Talysurf Surface Roughness Tester**

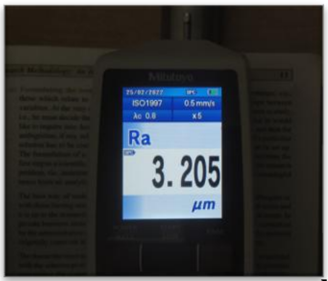

Figure 3.5. **Tester displaying $R_a$value**

3.4 Tool Tip Temperature Measurement

Tool temperature is observed using IR thermometer. Infrared (IR) thermometers enable you to measure temperature quickly, at a distance, and without touching the object you're measuring (fig 3.6).An infrared thermometer is a thermometer which infers temperature from a portion of the thermal radiation sometimes called black-body radiation emitted by the object being measured.

Figure 3.6. **Measuring tool tip temperature while machining**

Table 3.1: Observations Table

Expt. No	Spindle Speed (RPM)	Feed Rate (mm/rev)	Depth of Cut (mm)	Initial Weight (grams)	Final Weight (grams)	Machining Time (seconds)	Tool Temperature (^oC)
1	835	0.45	0.25	1912	1906	7.98	55
2	835	0.75	0.5	1906	1892	4.79	67
3	835	1	0.75	1892	1874	3.59	112
4	1330	0.45	0.5	1874	1860	5.01	47
5	1330	0.75	0.75	1860	1831	3.00	102

6	1330	1	0.25	1959	1955	2.25	66
7	2000	0.45	0.75	1935	1912	3.34	177
8	2000	0.75	0.25	1955	1949	2.00	82
9	2000	1	0.5	1949	1935	1.5	76

4. RESULTS AND DISCUSSION

In this chapter the experimental results of Material Removal Rate (MRR), Surface Roughness (R_a, R_q, R_z) and Tool Temperature are analysed using ANOVA method. Mathematical models and Residual plots are obtained for all the response factors. The focus of the work is to identify the optimal combination of process parameters that concurrently maximizes the material removal rate and minimizes the surface roughness and tool temperature.

Table 4.1: Experimental Results

Expt No.	Spindle Speed (RPM)	Feed Rate (mm/rev)	Depth Of Cut (mm)	MRR (mm^3/sec)	R_a (µm)	R_q (µm)	R_z (µm)	Tool Temperature (°C)
1	835	0.45	0.25	94.05	3.16	3.75	15.56	55
2	835	0.75	0.5	365.76	3.42	4.11	16.37	67
3	835	1	0.75	627.03	4.26	5.21	22.58	112
4	1330	0.45	0.5	349.56	2.71	3.266	12.64	47
5	1330	0.75	0.75	1206.8	9.13	10.77	39.46	102
6	1330	1	0.25	221.94	20.08	23.51	83.08	66
7	2000	0.45	0.75	863.57	4.42	5.20	20.54	177
8	2000	0.75	0.25	375.46	14.87	18.64	76.16	82
9	2000	1	0.5	1168.1	13.94	16.67	61.11	76

4.1 ANOVA

ANOVA results of the responses for MRR, R_a, R_q, R_z, Tool temperaturewere given in tables numbered from7 to11 respectively. From the results it is observed that depth of cut (D.O.C) is the most significant factor for the MRR and Tool temperature. And,feed rate (F. R)is most significant factor for the surface roughness (R_a, R_q, R_z).

Table 4.2: ANOVA for MRR

Source	DF	Adj SS	Adj MS	F	P	% Contribution
S. Speed	1	290528	290528	2.28	0.270	21.905
F. R	1	83991	83991	0.66	0.502	6.33
D.O.C	1	670639	670639	5.26	0.149	50.56
S. Speed * S. Speed	1	3755	3755	0.03	0.879	0.28
F. R * F. R	1	14256	14256	0.11	0.770	1.07
D.O.C*D.O.C	1	7938	7938	0.06	0.826	0.59
Error	2	254776	127388			19.21
Total	8	1326252				100

Table 4.3: ANOVA for R_a

Source	DF	Adj SS	Adj MS	F	P	% Contribution
S. Speed	1	83.562	83.562	25.54	0.037	25.54
F. R	1	130.632	130.632	39.93	0.024	39.94
D.O.C	1	68.653	68.653	20.98	0.045	20.98
S. Speed * S. Speed	1	29.518	29.518	9.02	0.095	9.08
F. R * F. R	1	0.772	0.772	0.24	0.675	0.23
D.O.C*D.O.C	1	13.819	13.819	4.22	0.176	4.22
Error	2	6.544	3.272			2.00

Total	8	327.121				100

Table 4.4: ANOVA for R_q

Source	**DF**	**Adj SS**	**Adj MS**	**F**	**P**	**% Contribution**
S. Speed	1	125.496	125.496	43.68	0.022	26.85
F. R	1	183.460	183.460	63.86	0.015	39.26
D.O.C	1	101.863	101.863	35.45	0.027	21.79
S. Speed * S. Speed	1	36.236	36.236	12.61	0.071	7.75
F. R * F. R	1	2.281	2.281	0.79	0.467	0.48
D.O.C*D.O.C	1	20.069	20.069	6.99	0.118	4.29
Error	2	5.746	2.873			1.22
Total	8	467.288				100

Table 4.5: ANOVA for R_z

Source	**DF**	**Adj SS**	**Adj MS**	**F**	**P**	**% Contribution**
S. Speed	1	1778.55	1778.55	286.09	0.003	28.78
F. R	1	2322.04	2322.04	373.51	0.003	37.58
D.O.C	1	1417.18	1417.18	227.96	0.004	22.93
S. Speed * S. Speed	1	298.36	298.36	47.99	0.020	4.82
F. R * F. R	1	78.83	78.83	12.68	0.071	1.27
D.O.C*D.O.C	1	330.67	330.67	53.19	0.018	5.35
Error	2	12.43	6.22			0.20
Total	8	6178.45				100

Table 4.6: ANOVA for Tool temperature

Source	**DF**	**Adj SS**	**Adj MS**	**F**	**P**	**% Contribution**
S. Speed	1	1700.2	1700.2	2.85	0.234	13.53
F. R	1	104.2	104.2	0.17	0.717	0.82
D.O.C	1	5890.7	5890.7	9.86	0.088	46.89
S. Speed * S. Speed	1	845.5	845.5	1.42	0.356	6.73
F. R * F. R	1	45.7	45.7	0.08	0.808	0.36
D.O.C*D.O.C	1	2544.2	2544.2	4.26	0.175	20.25
Error	2	1194.9	597.44			9.51
Total	8	12560.9				100

4.2 Mathematical Model and Residual Plots

Regression analysis has been conducted to prepare models for the responses. The residual plots were drawn to analyse the distribution of errors. From the normality and versus fits and order plots for responses, it is concluded that the residuals are not following normality and they are not showing any regular pattern hence the models developed are accurate and adequate.

4.2.1 Regression Equation for MRR

MRR = -1902 + 0.75 Spindle Speed + 2065 Feed Rate + 2345 Depth of Cut
- 0.000131 Spindle Speed*Spindle Speed - 1127 Feed Rate*Feed Rate
- 1008 Depth of Cut*Depth of Cut

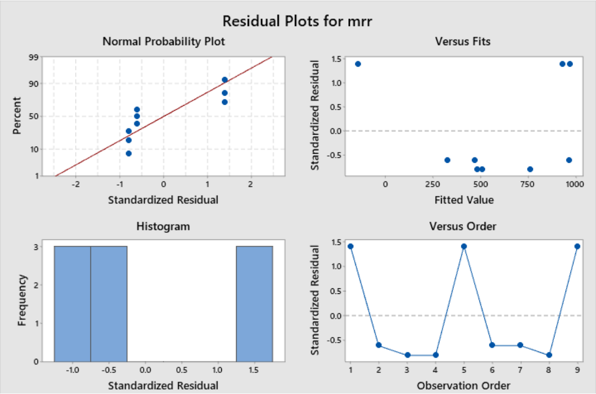

Figure 4.1.Residual plot graphs for MRR

4.2.2 Regression Equation for R_a

R_a = -22.0 + 0.0394 Spindle Speed + 29.0 Feed Rate - 55.6 Depth of Cut
- 0.000012 Spindle Speed*Spindle Speed - 8.3 Feed Rate*Feed Rate
+ 42.1 Depth of Cut*Depth of Cut

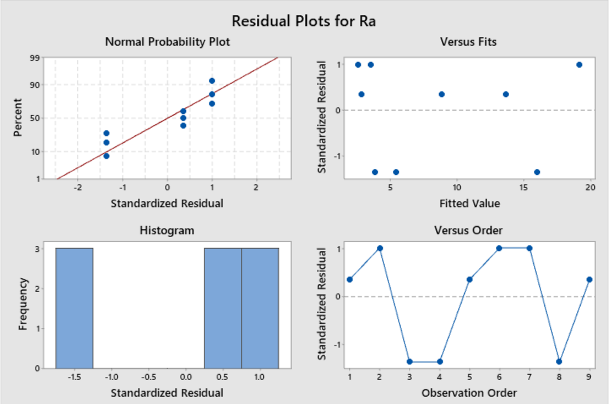

Figure 4.2.Residual plot graphs for R_a

4.2.3 Regression Equation for R_q

R_q = -26.4 + 0.0444 Spindle Speed + 40.8 Feed Rate - 67.2 Depth of Cut
- 0.000013 Spindle Speed*Spindle Speed - 14.3 Feed Rate*Feed Rate
+ 50.7 Depth of Cut*Depth of Cut

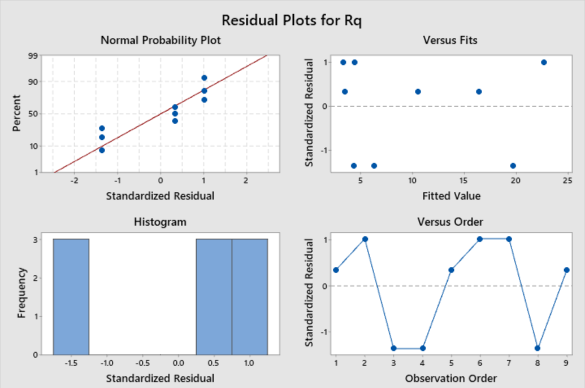

Figure 4.3.Residual plot graphs for R_q

4.2.4 Regression Equation for R_z

R_z = -86.9 + 0.1344 Spindle Speed + 193.1 Feed Rate - 267.2 Depth of Cut
- 0.000037 Spindle Speed*Spindle Speed - 83.8 Feed Rate*Feed Rate
+ 205.7 Depth of Cut*Depth of Cut

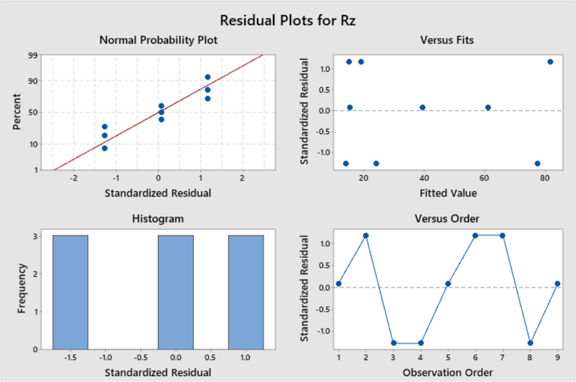

Figure 4.4. **Residual plot graphs for R_z**

4.2.5 Regression Equation for Tool Temperature

Tool Temperature = 255 - 0.148 Spindle Speed - 108 Feed Rate - 445 Depth of Cut
+ 0.000062 Spindle Speed*Spindle Speed + 64 Feed Rate*Feed Rate
+ 571 Depth of Cut*Depth of Cut

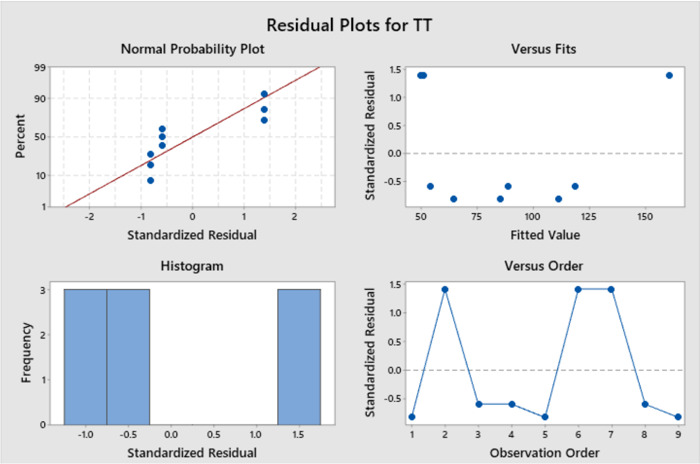

Figure 4.5. **Residual plot graphs for Tool temperature**

4.3 Response Surface Optimization

Response Surface Methodology, RSM (also known as Response Surface Modeling) is a technique to optimize the response(s) when two or more quantitative factors are involved. The dependent variables are known as responses, and the independent variables or factors are primarily known as the predictor variables in response surface methodology.

Response Optimization for all output parameters is achieved by fixing goals (either minimum or maximum) to each output parameter. Minitab is used to run the Response Surface Optimization technique. Table shows the considered parameters to run the optimization technique. Later, the optimal input parameters are displayed in the minitab and are shown below

Table 4.7: Inputs to obtain Optimized values

Response	Goal	Lower	Target	Upper	Weight	Importance
Tool Temperature	Minimum		47.00	177.000	1	1
R_z	Minimum		12.64	83.085	1	1
R_q	Minimum		3.27	23.513	1	1
R_a	Minimum		2.72	20.083	1	1
MRR	Maximum	94.05	1206.80		1	1

Table 4.8: Optimum Conditions (Parameters)

Variable	Setting
Spindle Speed	1112.69
Feed Rate	0.56
Depth of Cut	0.61

The optimal output values obtained by using optimized input parameters are displayed in minitab in the form of a graph as shown below.

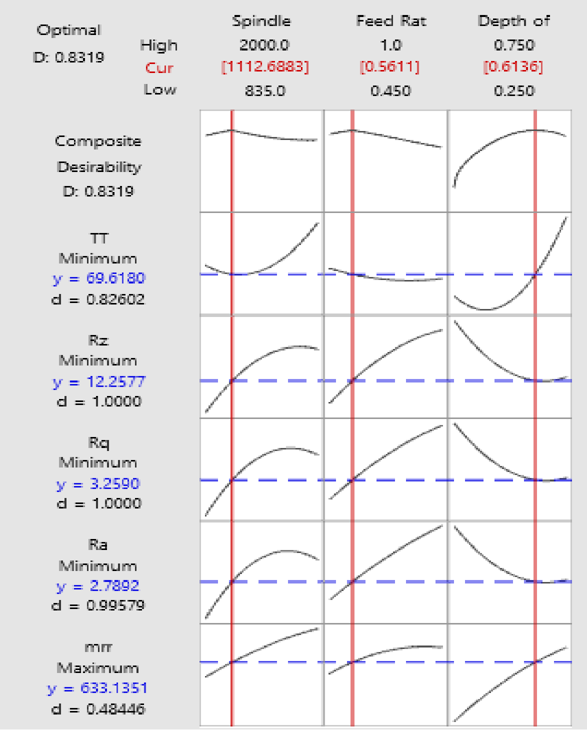

Figure 4.6.Optimization Plot

4.4 Results Of Confirmation Experiment

The purpose of this confirmation experiment is to verify the improvement in the quality characteristics.
The optimal values of output parameters for the obtained optimum conditions (from table 5.9) are made to compare with the experimental results which were obtained by conducting the experiment with the optimal machining parameters.

Table 4.9: Confirmation Experiment Results

Level	Optimal Result	Experiment Result	% Error
MRR	633.1351	633.5586	0.06
R_a	2.7892	2.3765	-14.79
R_q	3.2590	3.1540	-3.22
R_z	12.2577	12.2951	0.30
Tool Temperature	69.6180	68.5656	-1.93

The percentage of error between the optimal and experimental values of multiple performance characteristics during the confirmation experiments is almost within 5%. So, we can say that improvement in quality characteristics has been verifies by confirmation experiment**.**

5 CONCLUSIONS

The conclusions arrived at the end of this work are as follows:

1. From this analysis, it is revealed that depth of cut is the most influencing factor for Material Removal Rate and Tool Temperature (50.56% and 46.89% respectively).

2. And also, Feed Rate is the most influencing factor for Surface Finish (39.94%, 39.26%, 37.58% are contributions for R_a, R_q,R_z respectively).

3. The Regression models prepared for all the responses showed good agreement with the experimental results as they followed normality and constant variance hence the models prepared can be used effectively for the future prediction of responses.

4. The percentage error between the optimal and experimental values of the multiple performance characteristics during the confirmation experiments is almost within 5%.

5. The value of multiple performance characteristics obtained from confirmation experiment is within the 95% confidence interval of the optimum condition.

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