American Journal of Mechanical and Industrial Engineering
2022; 7(4): 53-62
http://www.sciencepublishinggroup.com/j/ajmie
doi: 10.11648/j.ajmie.20220704.11
ISSN: 2575-6079 (Print); ISSN: 2575-6060 (Online)

Optimization of Process Parameters Using Response Surface Methodology for SAE8620

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To cite this article:
Chinmay Anil Tornekar, Mayur Laxmanrao Jadhav, Sachin Chandrakant Borse. Optimization of Process Parameters Using Response Surface Methodology for SAE8620. *American Journal of Mechanical and Industrial Engineering*. Vol. 7, No. 4, 2022, pp. 53-62.
doi: 10.11648/j.ajmie.20220704.11

Received: August 3, 2022; **Accepted**: August 23, 2022; **Published**: October 17, 2022

Abstract: The present study is carried for the optimization of the process parameters in order to reduce the monthly In-House Rejection Rate, improving quality and enhancement of production thereby minimizing the consumer complaints. The component selected for study is Shift fork. A pareto Analysis Study clearly explains that I.D not ok contributes around 30% defects. This I.D Not OK included I.D Oversize, I.D Shift, I.D patch Mark & I.D Burn. Design of Experiments has been used to study the effect of Process parameters like speed, feed and no of passes on VMC and Honing Machine to determine the Surface Roughness, I. D oversize and I. D shift of SAE 8620 Fork. A mathematical Model has been generated in terms of the above process parameters the effect of these parameters on Surface roughness, I. D oversize and I. D shift has been Investigated using Response Surface Methodology (RSM). Surface Plot and Contour plots were constructed to determine the optimum conditions for the desired Output. The Developed Prediction shows that Cutting speed is the influential factor for all three Output Results, and No. of Pass is main factor is important for I. D shift. These results thus provided the optimal solution, thereby reducing the Customer Complaint and minimizing the Rejection Rate in the Company.

Keywords: SAE8620, DOE, RSM, Optimization, In-House Rejection, VMC, Honing

1. Introduction

In the world of manufacturing industries, production plays a major role forming it as one of the key measures of success. Secondly, efficiency is one of the factors which come into account for maximizing output from optimum input. However, for finding a balance between production and efficiency investigation in the improvement of process parameters of any material may lead to gain higher profit with successful outcome for the industries. Also, there is a need for selection of appropriate tools along with optimal machining conditions for dimensional accuracy and surface finish of the material. In order to reduce the rejection rate of the material various machining operations can be done. Statistical experimentation can be done for the validation of the results. The Small-Scale Manufacturing Industry in which the study was carried out faced lot of problems related to rejection from customers, so firstly an Analysis was carried out using Pareto chart to identify the critical defects. The results indicated I.D not ok was major Concern and a goal to focus on. Along with it 4M study was also done this help to identify the small gaps. Then taking advise from Machine shop experts and study results the DOE was carried on VMC and Honing Machine. Various trials were conducted which helped to Optimize the results at the end.

2. Literature Survey

The paper of Dhirendra Barodia et al. [1] investigates on Multi-Objective Optimization of Machining parameters by using Response Surface Methodology E-19 Alloy Steel Metal, the study was carried for three controllable Factors i.e., speed, feed and Depth of cut. The main goal was to find out which parameters have the highest metal extraction rate. This experiment additionally suggests that the material removal rate is very influenced first by the feed rate so depth of cut followed by spindle speed. It is clear from analysis that the effect of Feed rate spindle speed and Depth of cut on material removal rate (MRR) is 41.47%, 37.11% and 21.42.68% respectively.

Shivam Kumar Singh et al. [2] investigated the Modeling and Optimization of EDM process parameters on Machining of Inconel 686 using RSM. For conducting the experiments four input parameters like Spark Current, Pulse on Time, % of duty cycle and voltage has been considered and conductive Aluminum has been taken as Workpiece. Spark current, pulse on time, duty cycle and voltage significantly affect the MRR, TWR and surface roughness Ra, this is observed from analysis.

The paper of K. Devika Devi et al. [3] included Mathematical Modelling and Optimization of Turning Process Parameters Using Response Surface Methodology. The study was carried for four controllable Factors i.e., speed, feed, Depth of cut and Coolant Type. The Predicated Optimal setting ensured minimization of Surface Roughness and Maximization of MRR, Tool life and Machinability Index.

M. Pradeep Kumar et al. [4] studied about Response Surface Methodology, and concluded that RSM is appropriate Optimization Tool which can be used in process or Product Design. RSM is more useful for Researchers whose area is concerned with Optimization. It has main advantages like, NO of Experimental Runs can be reduced, and it can be able to detect parameter Interaction Effect on Response.

A. Balasubramanian et al. [5] studied the Optimization of Process parameters using Response Surface Methodology for the removal of Phenol by emulsion liquid membrane. The effects of process parameters namely, Surfactant concentration, membrane or organic to internal phase ratio (M/I) and emulsion to an external phase ratio (E/E) on the removal of phenol were optimized using a response surface method. The optimum conditions for the extraction of phenol using Response surface methodology were: surfactant concentration – 4.1802 %, M/I ratio: 0.9987 (v/v), and E/E ratio: 0.4718 (v/v). Under the optimized condition the maximum phenol extraction was found to be 98.88% respectively.

The study of Srinivasan, A. et al. [6] discusses the influence of cutting variables such as feed, cutting speed and depth of cut at work-tool interface zone temperature and surface finish while machining aluminum alloy LM6 reinforced with Al_2O_3 metal matrix composites.

The present work of Subramanian M et al. [7] deals with the study and development of a regression model to predict surface roughness in terms of geometrical parameter, nose radius of cutting tool TNMG insert and machining parameters, cutting speed and cutting feed rate for machining AL7075-T6, using Response Surface Methodology (RSM).

The objective of the present work of Wasif M. G., Safiulla et al. [8] was to investigate the effects of the various machining (turning) process parameters on the machining quality and to obtain the optimal sets of process parameters so that the quality of machined parts can be optimized.

The aim of study of is Ghazi Abu Taher et al. [9] to find out the effective way of improving the quality and productivity of a production line in manufacturing industry. The objective is to identify the defect of the company and create a better solution to improve the production line performance.

The paper of Ghani J. A., et al. [10] studied about the Taguchi method used for optimization for process parameters to reduce the rejection and maximize the output.

Mohammed T. Hayajneh, et al. [11] set experiments designed to begin the characterization of surface quality for the end-milling process have been performed. The objective of this study is to develop a better understanding of the effects of spindle speed, cutting feed rate and depth of cut on the surface roughness and to build a multiple regression model.

According to the study of Ho, K. H et al. [14], electrical discharge machining (EDM) is a well-established machining option for manufacturing geometrically complex or hard material parts that are extremely difficult-to-machine by conventional machining processes.

The paper of Mohan B. et al. [15] discusses about the electrical machining as a good option for machining, also it uses composite material to study the effect on output machining parameters.

3. Experimental Setup

3.1. Work Piece (Fork)

SAE8620 is a low carbon alloy steel having hardenability, toughness and were resistance surface rendering it extensively useful for all industrial sectors having automotive parts namely, shafts, crankshafts, gears and gearings.

3.2. Tooling

3.2.1. Hole Mill Cutter

A Hole-mill is normally an undersized reamer with a boring geometry i.e., the size of the hole-mill is normally 0.2-0.6mm more than the size of the drill so that there are no drill marks on the hole plus the hole axis is corrected for subsequent reaming operation.

3.2.2. Honing Tool

This Honing tool also called as an abrasive stone is used to produce good surface finish on workpiece by the simultaneous reciprocating and rotation action of Tool. It is used to remove material in microns.

3.3. Machine

3.3.1. VMC (Vertical Milling Center) [12]

Milling is a method of machining which uses rotary cutters for the removal of material by advancing cutter into a work piece.

3.3.2. Honing Machine

Honing is a method of internal grinding used to achieve precise geometry and surface finish for a particular metal work piece.

In the present study, the major input (process) parameters namely work speed, feed rate, depth of cut and number of passes influence the output (response) parameters namely surface roughness, internal diameter shift, internal diameter oversize of a work piece are considered.

4. Methodology

To conduct this research, an automotive company was selected which has been manufacturing various automotive parts from last 25 years. The company was consistently facing problem of part rejection at machining stage of their production line. To identify the problem cause effect study was done and from the observations it was identified that internal diameter shift, internal diameter oversize and surface roughness were the major cause of part rejection. To propose a solution for the same statistical analysis using RSM method has been carried out.

4.1. RSM (Response Surface Methodology) [13]

Response surface methodology (RSM) includes optimization procedures for the settings of factorial variables, such that the response reaches a desired maximum or minimum value. By careful design of experiments, the objective is to optimize a response (output variable) which is influenced by several independent variables (input variables). An experiment is a series of tests, called runs, in which changes are made in the input variables in order to identify the reasons for changes in the output response.

4.2. The Steps to Perform RSM Are as Follows

1) Choose the parameter to be studied and range of independent parameters.
2) Collecting the Experimental Data of these parameters with interaction response parameter.
3) Analysis the data by using Response Surface Method.
4) Build by the response model.

5. Performance Analysis

5.1. Experimental Values Obtained from Milling & Honing

Table 1. *Independent Parameters and their Range.*

Sr. No	Parameters	Range
1	Speed (Rpm)	350-950
2	Feed Rate (mm/rev)	50-120
3	No of Passes	1 - 3

Table 2. *Experimental values obtained from Milling and honing machine.*

Cutting Speed	Feed rate	No of Passes	Ra	I. D Oversize	I. D Shift
350	50	3	1.25	16.025	0.018
650	85	2	2.9	16.034	0.012
350	50	1	1.25	16.025	0.005
650	85	1	2.9	16.034	0.007
650	120	2	3.23	16.038	0.014
350	85	2	1.26	16.027	0.013
650	50	2	3.06	16.032	0.013
650	85	2	2.9	16.034	0.013
650	85	2	2.9	16.034	0.013
650	85	2	2.9	16.034	0.013
950	120	3	4.32	16.037	0.022
950	120	1	4.32	16.037	0.01
350	120	3	2.36	16.029	0.019
350	120	1	2.36	16.029	0.011
650	85	2	2.9	16.034	0.013
650	85	3	2.9	16.034	0.02
950	50	3	4.02	16.032	0.02
650	85	2	2.9	16.034	0.015
950	85	2	4.03	16.034	0.016
950	50	1	4.02	16.032	0.014

5.2. Results and Discussion

1) Response Surface for Surface Roughness (Ra):

Table 3. *Coded Coefficients of Ra.*

Term	Coeff	SE Coeff	T-Value	P-Value	VIF
Constant	2.8902	0.0403	71.71	0.000	
Cutting Speed	1.223	0.038	32.19	0.000	1
Feed rate	0.299	0.038	7.87	0.080	1
No of Passes	0	0.038	0	1.000	1
Cutting Speed*Cutting Speed	-0.2062	0.0672	-3.07	0.123	1.56
Feed rate*Feed rate	0.2937	0.0672	4.37	0.1236	1.56
Cutting Speed*Feed rate	-0.2025	0.0425	-4.77	0.2156	1

5.2.1. ANNOVA for Surface Finish (Ra)

Table 4. *ANNOVA for Surface Finish (Ra).*

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	6	16.46	2.7433	190	0.0000
Linear	3	15.8513	5.2838	365.94	0.0000
Cutting Speed	1	14.9573	14.9573	1035.91	0.0000
Feed rate	1	0.894	0.894	61.92	0.1023
No of Passes	1	0	0	0	1.0000
Square	2	0.2806	0.1403	9.72	0.0030
Cutting Speed*Cutting Speed	1	0.1361	0.1361	9.43	0.0090
Feed rate*Feed rate	1	0.2761	0.2761	19.12	0.236
2-Way Interaction	1	0.328	0.328	22.72	0.01236
Cutting Speed*Feed rate	1	0.328	0.328	22.72	0.01423
Error	13	0.1877	0.0144		
Lack-of-Fit	8	0.1877	0.0235	*	*
Pure Error	5	0	0		
Total	19	16.6477			

After doing the ANOVA in Minitab 15 the value of R2 & R2 (adj) are obtained, they are as follows,
S = 0.120, R2 = 98.87%, R2 (adj) = 98.35%. The R2 coefficient indicates the goodness of fit for the model. In this case, the value of the coefficient (R2 = 0.987) indicates that 98.87% of the total variability is explained by the model after considering the significant factors.

5.2.2. Regression Equation for Surface Finish (Ra)

Ra = -0.787 + 0.00870 Cutting speed -0.01969 Feed Rate -0.01969 Feed Rate – 0.00000 Cutting Speed*Cutting Speed +0.000240 Feed Rate* Feed Rate – 0.000019 Cutting Speed * Feed Rate

5.2.3. Residual Plots for Ra Value

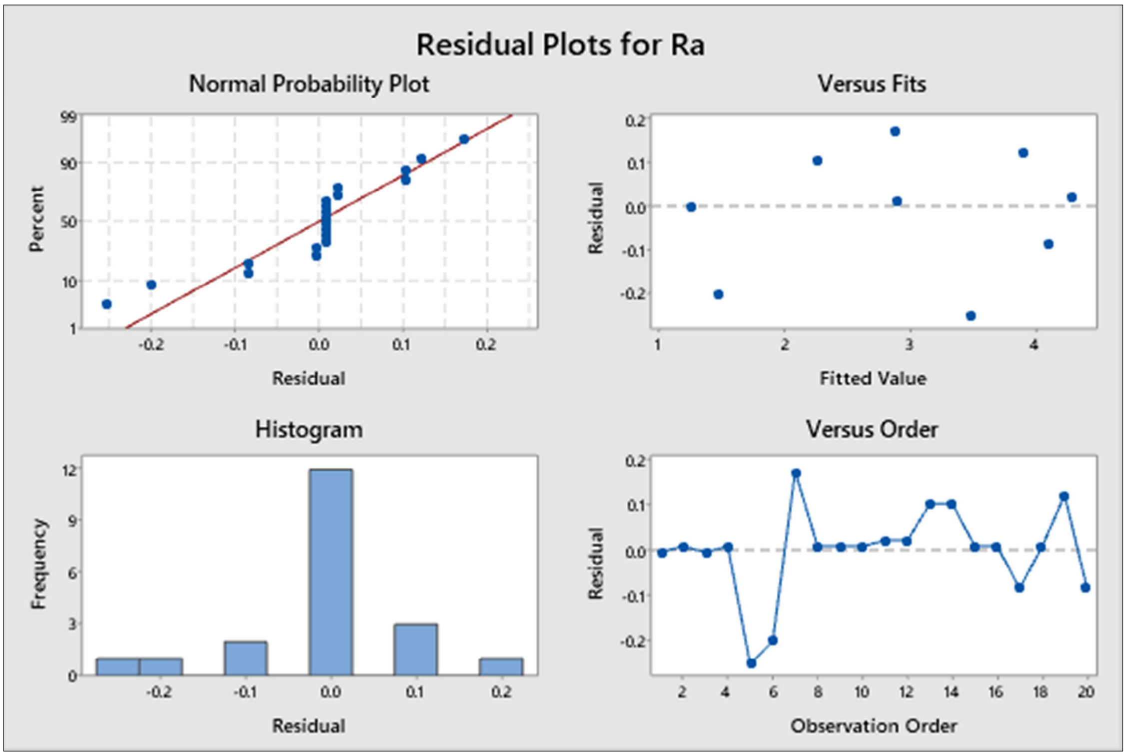

Figure 1. *Residual Plots for Ra Value.*

The Figure 1 shows four different types of plots. (A) Normal probability plot, (B) Residuals versus fitted values, (C) Histogram and (D) Residuals versus observation order. From the Normal probability plot it is inferred that as residuals value are close to the fitted line the residuals are normally distributed.

5.2.4. Contour Plot for Ra

This Contour Plot as shown in Graph 5.11 shows the relation between feed rate and Cutting Speed to predicate the value of Surface finish of Workpiece. The Darker Green regions shows the surface finish with higher values, while the minimum values of Surface finish is obtained in darker blue regions. Thus, optimum surface finish can obtain at lower speed and lower cutting Speed.

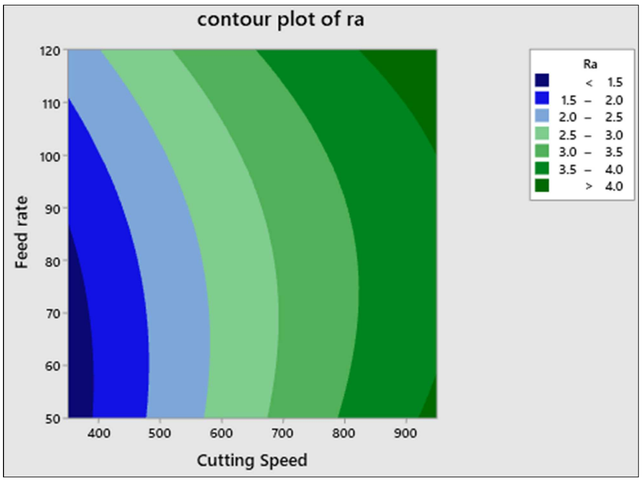

Figure 2. *Contour Plots for Ra Value.*

5.2.5. Surface Plot for Ra

This 2D Surface Plot as shown in Graph 5.12 shows the relation between feed rate and Cutting Speed to predicate the value of Surface finish of Workpiece. The values of lower surface finish are obtained at lower left corner, which corresponds with both low values of cutting speed and feed rate. Similarly, the high value of Surface finish is obtained at upper right corresponding to high values of feed rate and cutting Speed.

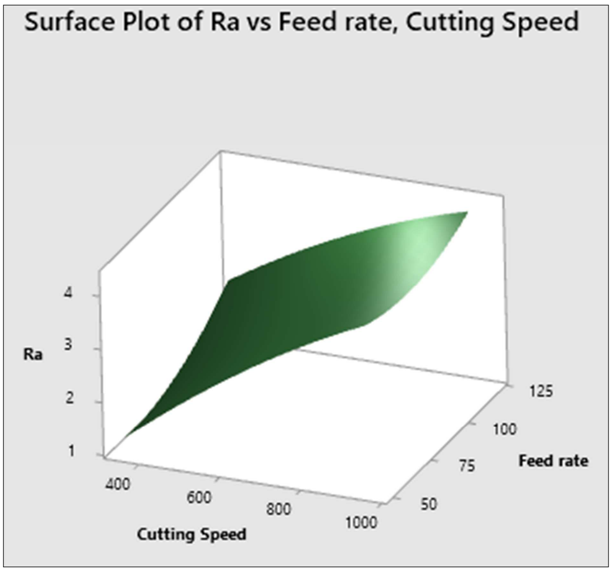

Figure 3. *Surface Plots for Ra Value.*

5.3. I. D Oversize

Table 5. *Coded Coefficients for I. D Oversize.*

Term	Coeff	SE Coeff	T-Value	P-Value	VIF
Constant	16.0341	0.0001	143138.13	0.000	
Cutting Speed	0.0037	0.000106	35.03	0.012	1
Feed rate	0.0024	0.000106	22.72	0.169	1
No of Passes	0	0.000106	0	1.000	1
Cutting Speed*Cutting Speed	-0.00388	0.000187	-20.76	0.041	1.56
Feed rate*Feed rate	0.000625	0.000187	3.35	0.156	1.56
Cutting Speed*Feed rate	0.00025	0.000118	2.12	0.234	1

5.3.1. ANNOVA for I. D Oversize

Table 6. *ANNOVA for I. D Oversize.*

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	6	0.000257	0.000043	384.77	0.000
Linear	3	0.000194	0.000065	581.26	0.000
Cutting Speed	1	0.000137	0.000137	1227.38	0.014
Feed rate	1	0.000058	0.000058	516.41	0.193
No of Passes	1	0	0	0	1.000
Square	2	0.000062	0.000031	280.17	0.000
Cutting Speed*Cutting Speed	1	0.000048	0.000048	430.79	0.045
Feed rate*Feed rate	1	0.000001	0.000001	11.21	0.146
2-Way Interaction	1	0	0	4.48	0.089
Cutting Speed*Feed rate	1	0	0	4.48	0.063
Error	13	0.000001	0		
Lack-of-Fit	8	0.000001	0	*	*
Pure Error	5	0	0		
Total	19	0.000259			

After doing the ANOVA in Minitab 15 the value of R2 & R2 (adj) are obtained, they are follows,
S = 0.00338, R2 = 99.44%, R2 (adj) = 99.18%.

5.3.2. Regression Equation for I. D Over-Size

I.D Oversize: 16.0070 + 0.000066 Cutting Speed -0.000034 Feed Rate + 0.000001 Feed Rate * Feed Rate

5.3.3. Residual Plots for I. D Over-Size

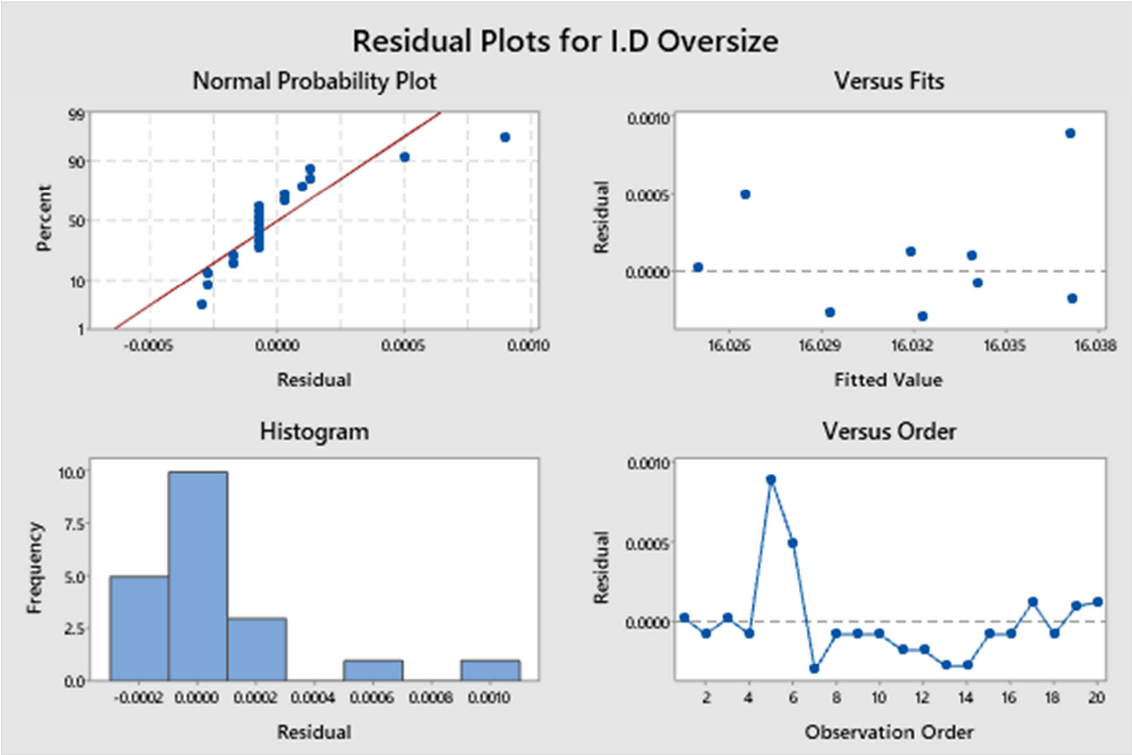

Figure 4. *Residual Plots for I. D Oversize.*

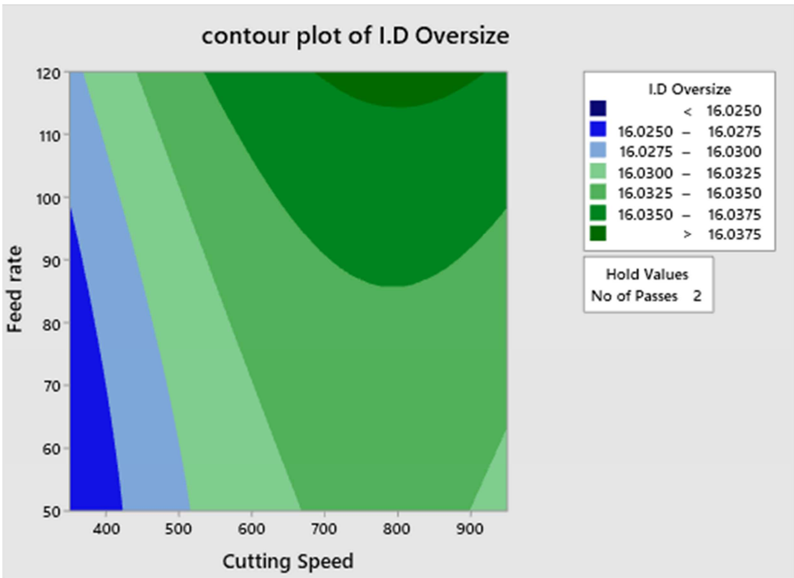

Figure 5. *Contour Plots for I. D Oversize.*

The Figure 4 shows four different types of plots. (A) Normal probability plot, (B) Residuals versus fitted values, (C) Histogram and (D) Residuals versus observation order. From the Normal probability plot it is inferred that as residuals value are close to the fitted line the residuals are normally distributed.

5.3.4. Contour Plot for Ra

This Contour Plot as shown in Figure 5 shows the relation between feed rate and Cutting Speed to predicate the value of I. D Oversize of Workpiece. The Darker Green regions shows the I. D Oversize with higher values, while the minimum values of I. D

Oversize is obtained in darker blue regions. Thus optimum I. D Oversize can obtained at lower speed and lower cutting Speed.

5.3.5. Surface Plot for Ra

This 2D Surface Plot as shown in Figure 6 shows the relation between feed rate and Cutting Speed to predicate the value of I. D Oversize of Workpiece. The values of I. D Oversize are obtained at lower left corner, which corresponds with both low values of cutting speed and feed rate. Similarly, the high value of I. D Oversize are obtained at upper right corresponding to high values of feed rate and cutting Speed.

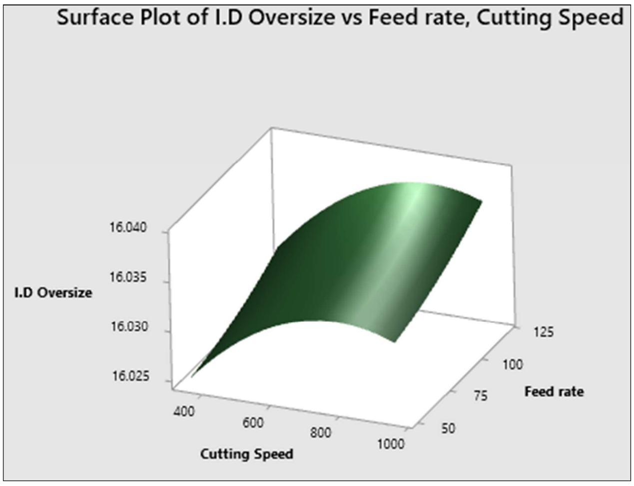

Figure 6. *Surface Plots for I. D Oversize.*

5.4. I. D Shift

Table 7. *Coded Coefficients for I. D Shift.*

Term	Coeff	SE Coeff	T-Value	P-Value	VIF
Constant	0.013209	0.000536	24.66	0.000	
Cutting Speed	0.0016	0.000493	3.25	0.063	1
Feed rate	0.0006	0.000493	1.22	0.251	1
No of Passes	0.0052	0.000493	10.56	0.006	1
Cutting Speed*Cutting Speed	0.001227	0.000939	1.31	0.221	1.82
Feed rate*Feed rate	0.000227	0.000939	0.24	0.814	1.82
No of Passes*No of Passes	0.000227	0.000939	0.24	0.814	1.82
Cutting Speed*Feed rate	-0.00113	0.000551	-2.04	0.068	1
Cutting Speed*No of Passes	-0.00038	0.000551	-0.68	0.511	1
Feed rate*No of Passes	0.000125	0.000551	0.23	0.825	1

5.4.1. ANNOVA for I. D Shift

Table 8. *ANNOVA for I. D Shift.*

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	0.000323	0.000036	14.77	0.000
Linear	3	0.0003	0.0001	41.15	0.000
Cutting Speed	1	0.000026	0.000026	10.55	0.009
Feed rate	1	0.000004	0.000004	1.48	0.251
No of Passes	1	0.00027	0.00027	111.41	0.000
Square	3	0.000012	0.000004	1.61	0.249
Cutting Speed*Cutting Speed	1	0.000004	0.000004	1.71	0.221
Feed rate*Feed rate	1	0	0	0.06	0.814
No of Passes*No of Passes	1	0	0	0.06	0.814
2-Way Interaction	3	0.000011	0.000004	1.56	0.259
Cutting Speed*Feed rate	1	0.00001	0.00001	4.17	0.068
Cutting Speed*No of Passes	1	0.000001	0.000001	0.46	0.511
Feed rate*No of Passes	1	0	0	0.05	0.825
Error	10	0.000024	0.000002		
Lack-of-Fit	5	0.000019	0.000004	4.02	0.076
Pure Error	5	0.000005	0.000001		
Total	19	0.000347			

After doing the ANOVA in Minitab 15 the value of R2 & R2 (adj) are obtained, they are as follows,
S = 0.0016020, R2 = 86.73%, R2 (adj) = 73.40%.

5.4.2. Regression Equation for Shift

I. D Shift= -0.00104 -0.000001 Cutting Speed + 0.0000048 Feed Rate +0.00480 No of Passes +0.000227 No of Passes * No of Passes -0.000001 Cutting Speed * No of Passes + 0.000004 Feed Rate * No of Passes

5.4.3. Residual Plots for I. D Shift

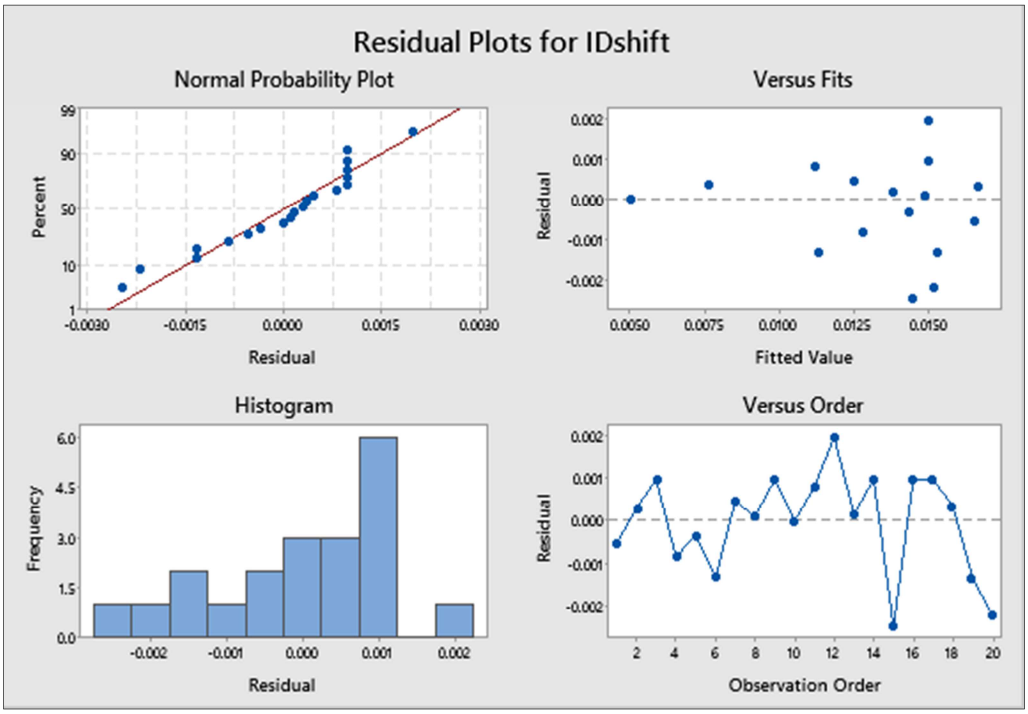

Figure 7. *Residual Plots for I. D Shift.*

The Figure 7 shows four different types of plots. (A) Normal probability plot, (B) Residuals versus fitted values, (C) Histogram and (D) Residuals versus observation order. From the Normal probability plot it is inferred that as residuals value are close to the fitted line the residuals are normally distributed.

5.4.4. Contour Plot for Ra

This Contour Plot as shown in Graph 5.23 shows the relation between feed rate, Cutting Speed and No of Pass with each other to predicate the value of I. D Shift of Workpiece. The Darker Green regions shows the I. D Shift with higher values, while the minimum values of I. D Shift is obtained in darker blue regions. Thus optimum I. D Oversize can obtained at lower speed and lower cutting Speed.

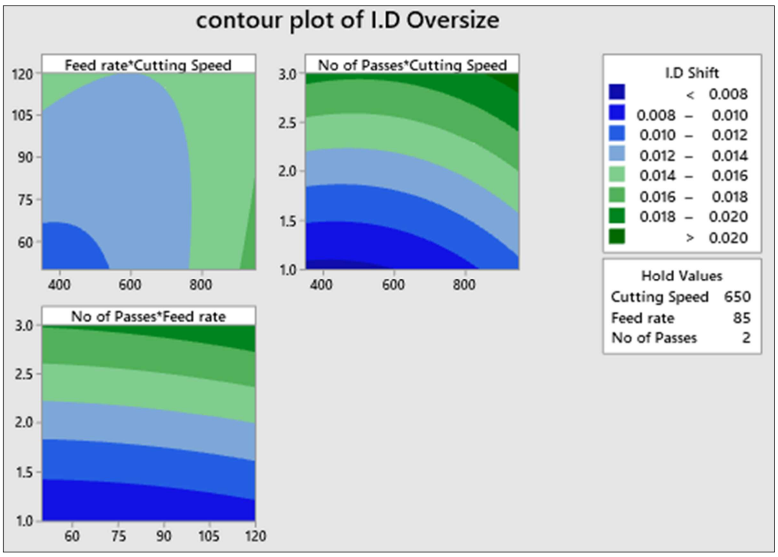

Figure 8. *Surface Plots for I. D Shift.*

6. Response Optimization for I. D Shift, I. D Oversize & Surface Finish

Table 9. *Response Optimization for I. D Shift, I. D Oversize & Ra.*

Solution	Cutting Speed	Feed Rate	No of Passes	I. D Shift Fit	I. D Oversize Fit	Ra Fit	Composite Desirability
1	350	50	1	0.006	16.025	1.2533	0.972

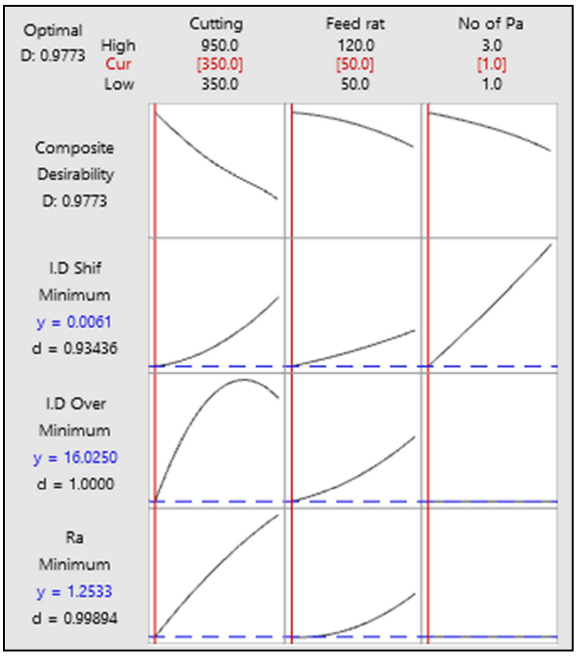

Figure 9. *Response Optimization for I. D Shift, I. D Oversize &Ra.*

The optimization plot as shown in Figure 9 found out the optimal solution at Cutting speed of 350 rpm, feed rate at 50 mm/rev and No of pass is 1. The Corresponding values of I. D Shift, I. D Oversize, and Ra are 0.006, 16.025 and 1.25 respectively. Also the Composite desirability of 0.97 which is closer to 0 predicts it as an optimal setting.

7. Conclusion

1) The Levels of the parameters were optimized with Respect to Surface Finish, I. D Shift & I. D oversize.
2) The optimization plot found out the optimal solution at Cutting speed of 350 rpm, feed rate at 50 mm/rev and No of pass is 1. The Corresponding values of I. D Shift, I. D Oversize, and Ra are 0.006, 16.025 and 1.25 respectively. Also the Composite desirability of 0.97 which is closer to 0 predicts it as an optimal setting.
3) These helped to minimize the customer Complaints, to minimize the defects, to maximize the productivity and for smooth process Flow.

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