Optimization OF Cutting Parameters In CNC Turning Machine Using TAGUCHI Method And ANOVA Technique

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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. As it is a post-process operation, it becomes both time-consuming and laborious. In addition, a number of defective parts can be found during the period of surface inspection, which leads to additional production cost. In the present work the cutting parameters (depth of cut, feed rate and cutting speed) have been optimized in CNC turning operation on stainless steel of grade ss316L with cementite carbide tool insert (CJ225P) and as a result of that the combination of the optimal levels of the above factors is obtained to get the lowest surface roughness and higher material removal rate using L9 orthogonal array. ANOVA is used to analyze the effects of cutting parameters on R_a and M.R.R. It has been found that the cutting speed = 500 rpm, feed = 0.1mm/rev, depth of cut = 0.2 mm, MRR = 64.5 cm3/min (maximum) and Ra = 0.998 micro-meters (minimum) are the optimum combination values. We also found that the depth of cut is the most influencing parameter affecting the material removal rate followed by feed and feed is the most influencing parameter affecting the surface roughness followed by depth of cut.

***Keywords* - Material removal rate (MRR), Surface Roughness (R_a), Computer Numerical Control (CNC), Design Of Experiments (DOE), Taguchi method, L9 Orthogonal Array, Analysis of variance (ANOVA).**

I. INTRODUCTION

For all machining process it is important to obtain accurate dimensions along with good surface quality and for achieving high production high MRR is important a machining process involves various parameters which can directly or indirectly affect surface roughness and material removal rate. Feed, speed, and depth of cut are very important parameter by varying which surface roughness and MRR can be affected. A good knowledge of optimizing the parameter can help in reducing the machining cost and improve product quality. Extensive study is done for optimization of the parameter so that better product is achieved. The current study is done on Taguchi method applied for most effective process parameters which are speed, Feed and depth of cut while machining stainless steel (ss316L) workpiece with cementite carbide tool insert (CJ225P). Three levels of the feed, three levels of speed, three values of the depth of cut, only one type of work material have been used to generate a total 9 readings in a single set.

Surface roughness remains the main indicator of machined component quality. A low surface roughness improves the properties, fatigue strength, corrosion resistance and aesthetic appeal of the product. A manufacturing engineer is expected to use his experience and use proper guidance to achieve the required surface finish. This must be done in a timely manner to avoid production delays, effectively to avoid defects, and to produce part of good quality. Therefore, in this situation, it is wise for the engineer or technician to use past experience to select parameters which will likely yield a surface roughness below that of the specified level by making an adjustment in the parameter as required.

1.1. TURNING OPERATION:

1. Turning is a form of machining, a material removal process, which is used to create rotational parts by cutting away unwanted material.
2. The Turning process requires a turning machine or lathe, workpiece, fixture and cutting tool.
3. Feed is the distance the cutting tool advances along the length of the work every revolution of the spindle.
4. Cutting speed may be defined as the speed at which the workpiece rotates.
5. Depth of cut is the perpendicular distance measured from the machined surface to the uncut surface of the workpiece.

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.

Fig. 1.1. CNC Lathe Machine used for machining.

II. EXPERIMENTATION AND METHODOLOGY

A CNC lathe machine was used for testing. Stainless steel 316L was used as a working material and the cementite carbide tool insert (CJ225P) was used as a cutting tool. The experience of this work was supported by the design of Taguchi (DOE) experiments and orthogonal matrix. It is necessary to distribute a large variety of experiments once the amount of process parameters is increased.

To solve this task, Taguchi uses a special design for orthogonal arrays to study the whole parameter area only with a small set of experiments. During this work, the three cutting parameters, cutting speed, depth of cut and feed of the experiment were considered and employed with L9 orthogonal array for experiment (Table 2.1.). Thus the response obtained from the tests conducted in accordance with the L9 matrix experiment was recorded and analyzed. DOE has been implemented to determine manufacturing standards that can lead to a better quality product. In this study, the maximum MRR and the minimum R_a values of the workpiece was examined.

2.1. TAGUCHI METHODOLOGY:

The Taguchi method involves reducing the variation in a process through the robust design of experiments. The overall objective of the method is to produce high-quality product at low cost to the manufacturer. The Taguchi method was developed by Genichi Taguchi. He developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied. Instead of having to test all possible combinations of the factorial design, the Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors most affect the product quality with a minimum amount of experimentation, thus saving time and resources. The Taguchi method is best used when there is an intermediate number of Variables (3 to 50), few interactions between variables, and when only a few variables contribute significantly.

2.2. PROCESS PARAMETERS AND THEIR LEVELS:

Table 2.1. Process Parameters and their levels.

Factors	Level-1	Level-2	Level-3
Cutting Speed (rpm)	400	450	500
Feed (mm/rev)	0.10	0.15	0.20
Depth of cut (mm)	0.4	0.8	1.2

2.3. L9 ORTHOGONAL ARRAY:

Table 2.2. L9 orthogonal array (Set of Experiments in coded form)

Run	Cutting Speed (rpm)	Feed (mm/rev)	Depth of cut (mm)
1.	1	1	1
2.	1	2	2
3.	1	3	3
4.	2	1	2
5.	2	2	3
6.	2	3	1
7.	3	1	3
8.	3	2	1
9.	3	3	2

III. EXPERIMENTAL DATA

3.1. MATERIAL SELECTION AND TOOL INSERT:

Selection of material is a crucial step in optimization procedure. Material should be selected which has wide applications in industry and also not in focus or in less focus, so it has scope for further optimization. Stainless steel is well known and popular material with different grades and the grade we used was ss316L and cementite carbide cutting tool insert.
Ss316L is typically used for construction of Exhaust manifolds, Furnace parts, Evaporators, Heat exchangers, Jet engine parts, Valve and pump parts, Chemical processing equipment, Pharmaceutical and photographic equipment, Tanks, Waste water treatment, Marine applications, Medical devices, Chemical and petrochemical industries.

Fig. 3.1. Stainless steel (ss316L)

Fig. 3.2. Cementite Carbide Tool Insert (CJ225P)

3.2. EXPERIMENTAL DETAILS AND SPECIFICATIONS:

Machine type	:	ACE CNC TUTOR Lathe
Maximum bar capacity	:	25 mm
Maximum spindle speed	:	4000 rpm
Cutting tool	:	CJ225P Tool Insert
Tool Material	:	Cementite Carbide
Work Material	:	Stainless steel 316L
Cutting Conditions	:	Dry environment
Diameter of Workpiece	:	20 mm
Length of cut	:	40 mm

3.2. MATERIAL REMOVAL RATE:

The MRR can be calculated by considering weight of the workpiece before and after machining process.

$$MRR = (W_i - W_f) / T$$

Where: W_i = weight of the workpiece before machining.
W_f = weight of the workpiece after machining.
T = Machining time.

3.3. SURFACE ROUGHNESS:

After conducting the experiments machined surface was measured at three different positions using roughness measuring instrument SJ-210 as shown in Figure 3.3 and the average surface roughness (R_a) values are recorded in micro-meters (µm).

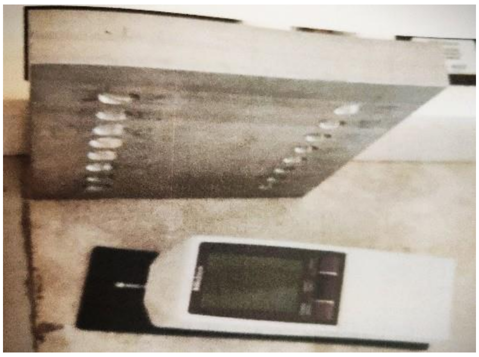

Fig. 3.3. SJ-210 Surface Tester.

IV. RESULTS AND DISCUSSIONS

4.1. DEVELOPMENT OF MATHEMATICAL MODEL:

A Second order polynomial is employed for developing the mathematical model for predicting weld pool geometry. If the response is well modelled by a linear function of the independent variables, then the approximating function is the first order model as shown in Equation.

$$Y = \beta_0 + \beta_1 X^1 Y^0 + \beta_2 X^2 Y^1 + \ldots + \beta_k X^k Y^{k-1} + €$$

A mathematical regression equation is developed for cycle time in every tool path and the graphs are plotted.

- Y is the corresponding response.
- X are the cutting parameters.
- (1, 2… k) are code levels of quantitative process variables.
- The terms are the second order regression coefficients
- Second term is attribute to linear effect.
- Third term corresponds to higher order effects.
- Fourth term includes the interactive effects of the process parameters.
- And the last term indicates the experimental error.
- All the estimated coefficients were used to construct the models for the response parameter and these models were used to construct the models for the response parameter and these models were tested by applying Analysis of Variance (ANOVA) technique F-ratio was calculated and compared, with the standard values for 95% confidence level. If the calculated value is less than the F-table values the model is consider adequate.

Regression equation generated for Ra is
Ra = – 0.20 – 0.00023 Vc + 10.03 F + 0.263 DOC

Table 4.1. F and P Values for Surface roughness.

R-sq = 96.27% R-sq (Pred) = 84.64% R-sq (adj.) = 94.03%

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	1.57698	0.52566	7.54	0.027
Vc	1	0.00082	0.00082	0.01	0.918
F	1	1.51002	1.51002	21.66	0.006
DOC	1	0.06615	0.06615	0.95	0.375
Error	5	0.34862	0.06972		
Total	8	1.92560			

From the above Table 4.1., we can see that P-value for the model is 0.027 which is lesser than the significance value of 0.05. Hence the model is significant. Feed is found to be the most influential parameter affecting the surface roughness with the lowest p-value (0.006, significant) among all three parameters followed by depth of cut.

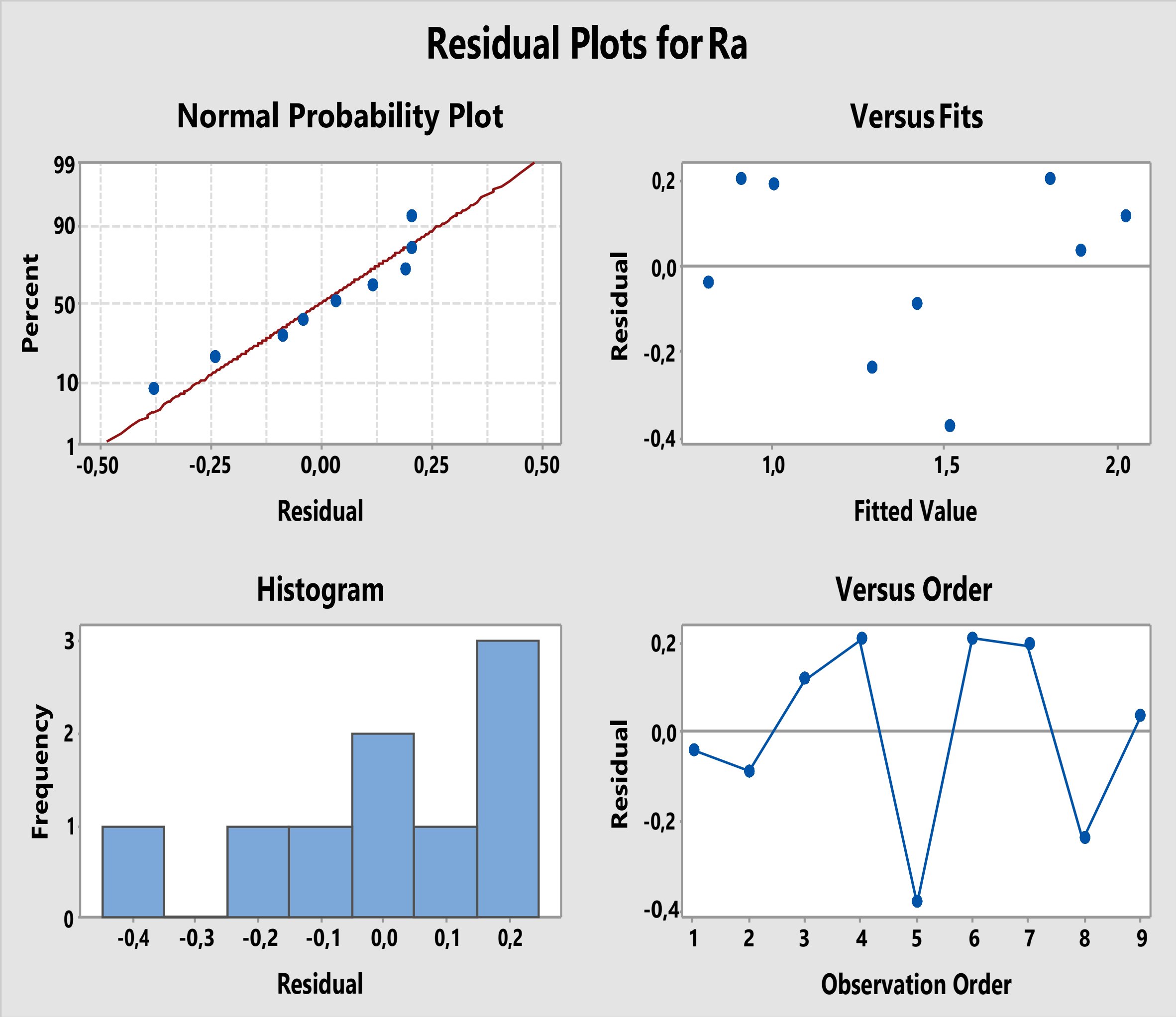

Fig. 4.1. Residual plots for surface roughness.

Regression equation generated for Material Removal Rate is
MRR = –63.0 + 0.0333 Vc + 333.3 F + 64.58 DOC

Table 4.2. F and P Values for Material removal rate.

R-sq = 81.90% R-sq (Pred) =45.72% R-sq (adj) =71.03%

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	5687.50	1895.83	42.99	0.001
Vc	1	16.67	16.67	0.38	0.566
F	1	1666.67	1666.67	37.79	0.002
DOC	1	4004.17	4004.17	90.80	0.000
Error	5	220.50	44.10		
Total	8	5908.00			

From the above Table 4.2., we can see that P-value for the model is 0.001 which is lesser than the significance value of 0.05. Hence the model is significant. Depth of cut is found to be the most influential parameter affecting the material removal rate with the lowest p-value (0.000, significant) among all three parameters followed by feed with the p-value (0.002, significant).

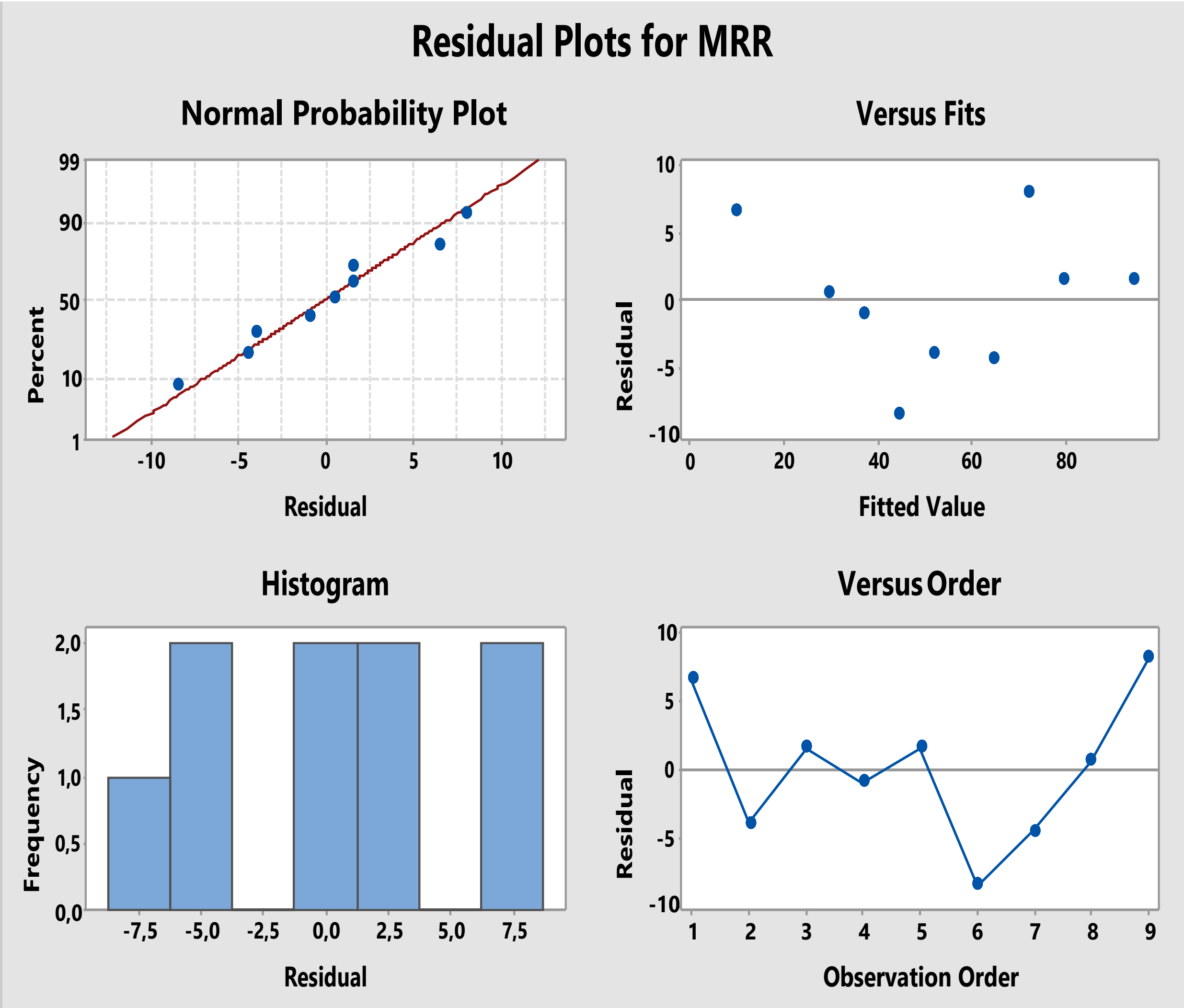

Fig. 4.2. Residual plots for material removal rate.

Table 4.3. List of Experimental and Predicted values.

Vc	F	DOC	Ra	MRR	FITS	FITS_1	RESI	RESI_1	SRES	SRES_1	COEF
400	0.10	0.4	0.77	16	0.81167	9.5	-0.041667	6.5	-0,25304	1.56957	-0.2033
400	0.15	0.8	1.33	48	1.41833	52.0	-0.088333	-4.0	-0,39364	-0.70877	-0.0002
400	0.20	1.2	2.14	96	2.02500	94.5	0.115000	1.5	0,69839	0.36221	10.0333
450	0.10	0.8	1.11	36	0.90500	37.0	0.205000	-1.0	0,91354	-0.17719	0.2625
450	0.15	1.2	1.13	81	1.51167	79.5	-0.381667	1.5	-1,70083	0.26579	
450	0.20	0.4	2.01	36	1.80333	44.5	0.206667	-8.5	1,05007	-1.71726	
500	0.10	1.2	1.19	60	0.99833	64.5	0.191667	-4.5	1,16398	-1.08663	
500	0.15	0.4	1.05	30	1.29000	29.5	-0.240000	0.5	-1,21943	0.10102	
500	0.20	0.8	1.93	80	1.89667	72.0	0.033333	8.0	0,16937	1.61624	

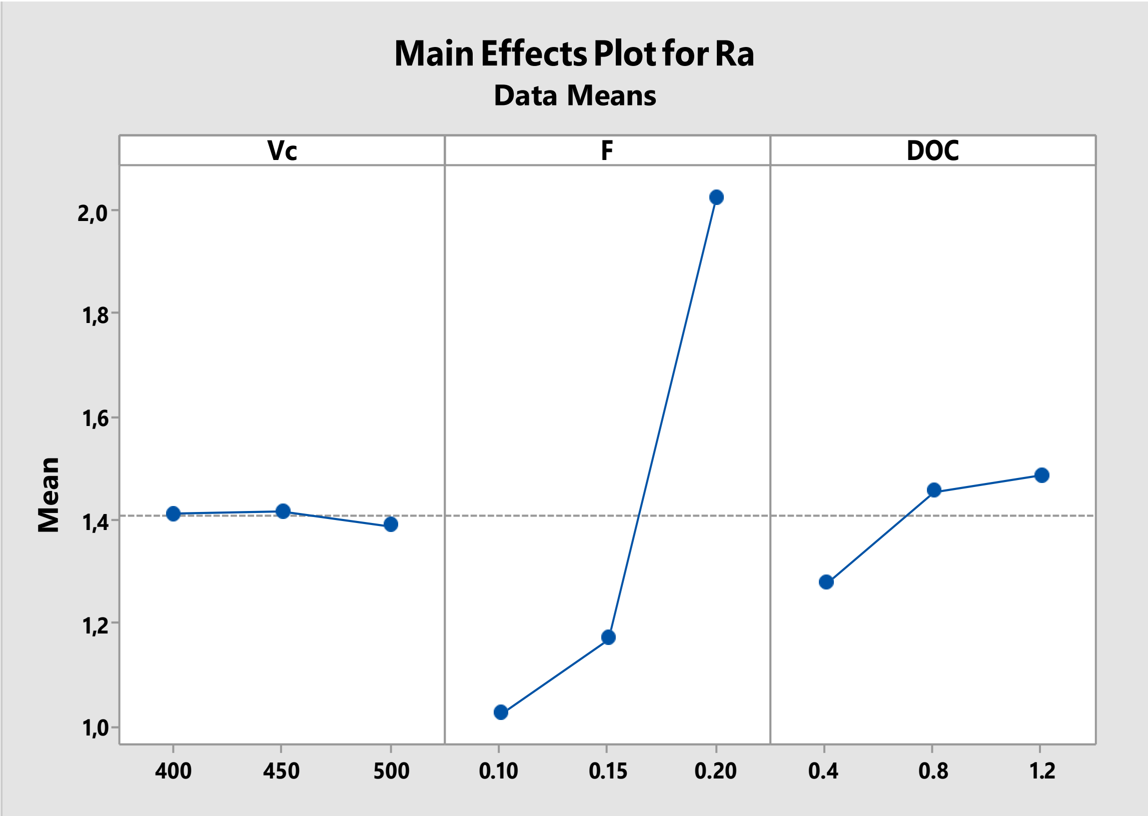

Fig. 4.3. Main effects plot for surface roughness.

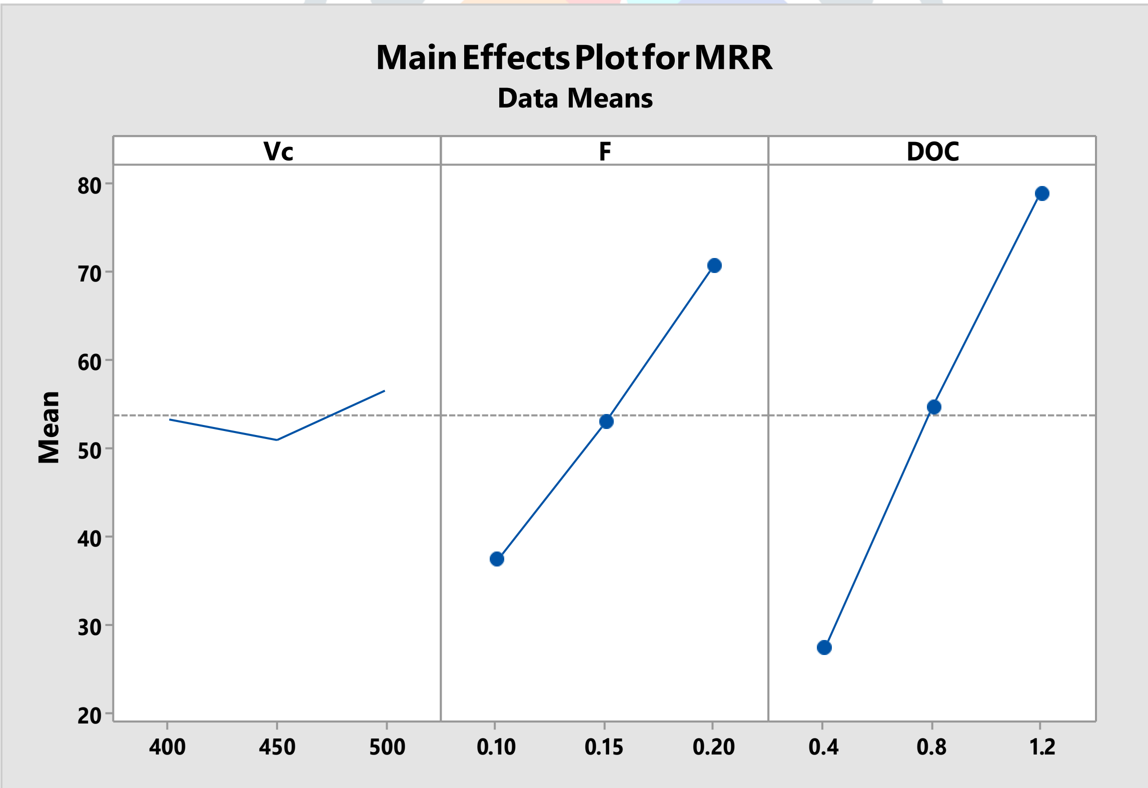

Fig. 4.4. Main effects plot for material removal rate.

4.2. RESPONSE OPTIMIZATION:

Many designed experiments involve determining optimal conditions that will produce the "best" value for the response.

4.2.1. RESPONSE OPTIMIZER

Response Optimizer - combinations and an optimization plot. The optimization plot is interactive; we can adjust variable input variable settings on the plot to search for more desirable solutions. Optimizer Provides with an optimal solution for the input

Use response optimization to help and identify the combination of input variable settings that jointly optimize a single response or a set of responses. Joint optimization must satisfy the all the responses in the set, which is measured by the composite desirability. Minitab calculates an optimal solution and draws a plot. The optimal solution serves as the starting point for the plot. This optimization plot allows to interactively changing the input variable settings to perform sensitivity analyses and possibly improve the initial solution.

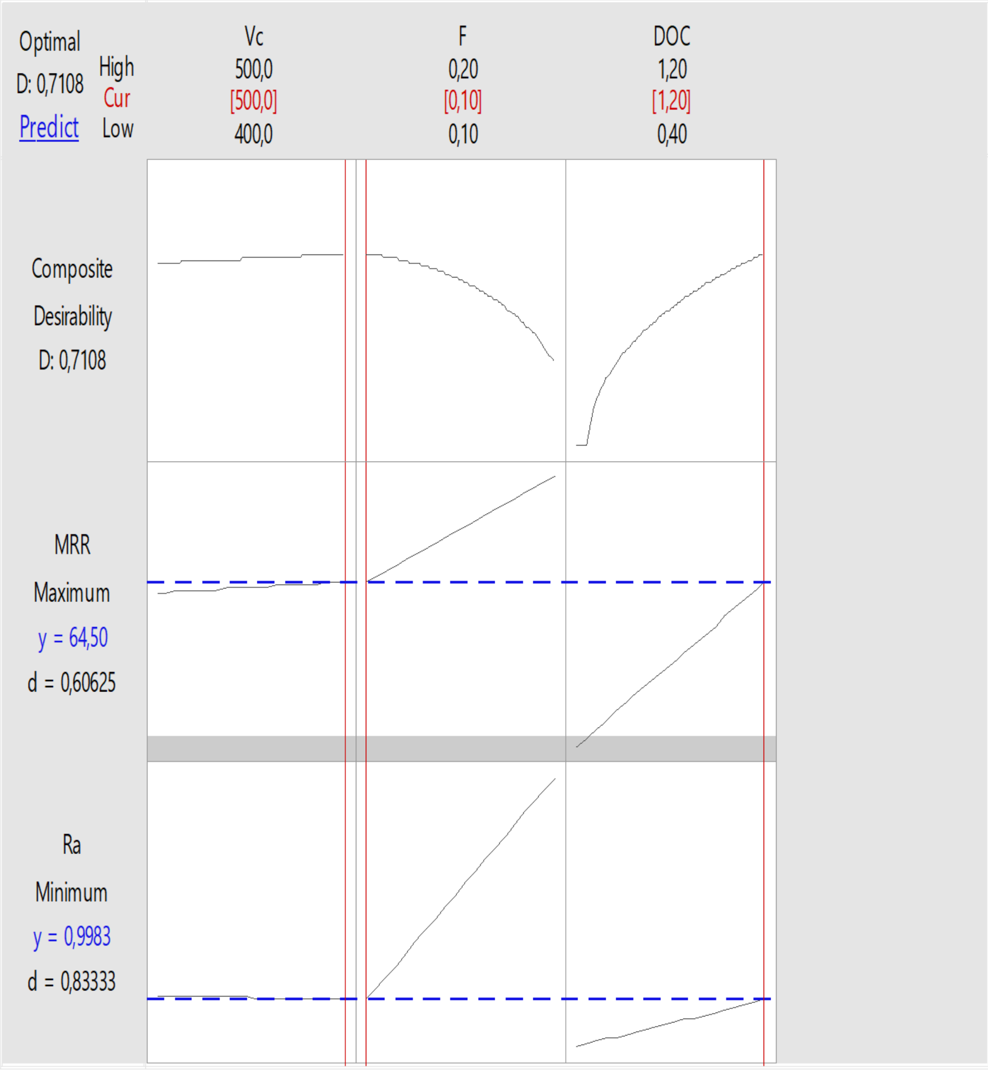

Fig. 4.5. Optimized plots for surface roughness and material removal rate.

The optimization plot as shown signifies the effect of each factor (columns) on the responses or composite desirability (rows). The vertical red lines on the graph represent the current factor settings. The numbers displayed at the top of a column show the current factor level settings in red). The horizontal blue lines and numbers represent the responses for the current factor level. Minitab calculates minimum surface roughness and maximum material removal rate.

4.3. EXPERIMENTAL RESULTS:

The optimum levels of parameters for minimizing surface roughness and maximizing material removal rate were determined from the response optimization. The best combinations are obtained with:

- Cutting Speed : 500 rpm
- Feed : 0.10 mm/rev
- Depth of cut : 1.2 mm

Table 4.4. Experimental Results.

Expt. no.	Cutting speed (R.P.M)	Feed (mm/rev)	Depth of cut (mm)	Surface Roughness (micro meters)	Material removal rate (cm^3/min)
1	400	0.10	0.4	0.77	16
2	400	0.15	0.8	1.33	48
3	400	0.20	1.2	2.14	96
4	450	0.10	0.8	1.11	36
5	450	0.15	1.2	1.13	81
6	450	0.20	0.4	2.01	36
7	500	0.10	1.2	1.19	60
8	500	0.15	0.4	1.05	30
9	500	0.20	0.8	1.93	80

CONCLUSION

In the present work, Response Optimization problem has been solved by using an optimal parameter combination of input parameters such as Cutting speed, Feed and Depth of Cut. These optimal parameters ensure in producing high material removal rate and minimized Surface Roughness of the workpiece material. This work produces a direct equation with the combination of controlled parameters which can be used in industries to obtain the optimized input parameters to be maintained during machining for required material removal at a pre-defined time along with a better surface finish. It is also found that the depth of cut is the influencing parameter most affecting the material removal rate and feed is the most influencing parameter affecting the surface roughness

Hence, we conclude that the optimal solution is obtained at:

A. Cutting Speed : **500 rpm**
B. Feed : **0.1 mm/rev**
C. Depth of cut : **0.2 mm**
D. M.R.R : **64.5 cm^3/min** (Maximum)
E. Ra : **0.998 micro-meters** (Minimum)

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