iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 8 **Issue:** V **Month of publication:** May 2020

DOI: http://doi.org/10.22214/ijraset.2020.5282

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 8 Issue V May 2020- Available at www.ijraset.com

Optimization of Cutting Parameters in Turning Aluminum by Maximizing MRR and Minimizing Cutting Forces

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***Abstract:** Nowadays aluminum is widely used in automobile industries, aerospace industries etc., due to its high weight to strength ratio. This project deals with optimization of cutting parameters on aluminium specimen in turning operation to obtain maximum MRR , minimum cutting forces and minimum work piece temperature using surface response analysis. The adequacy of the developed model is checked using Analysis of Variance (ANOVA) technique. By using the mathematical model the main and interaction effect of various process parameters on MRR, is studied. The developed model helps in selection of proper machining parameters for the specific material and also helps in achieving the desired material removal rate.*

***Keywords:** Optimization, Material removal rate, ANOVA*

I. INTRODUCTION

Turning is the removal of metal from the outer diameter of a rotating cylindrical work piece. Turning is used to reduce the diameter of the work piece, usually to a specified dimension, and to produce a smooth finish on the metal. Often the work piece will be turned so that adjacent sections have different diameters. Turning is the machining operation that produces cylindrical parts. In its basic form, it can be defined as the machining of an external surface:

1) With the work piece rotating.
2) With a single-point cutting tool and
3) With the cutting tool feeding parallel to the axis of the work piece and at a distance that will remove the outer surface of the work.

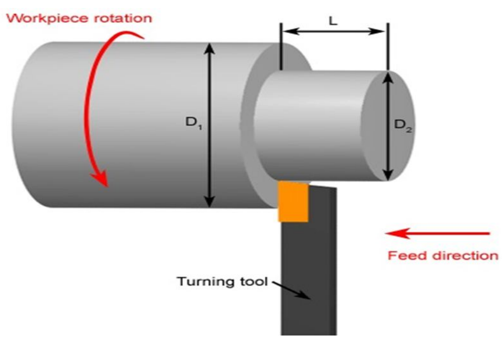

Figure 1: Adjustable parameters in turning operation

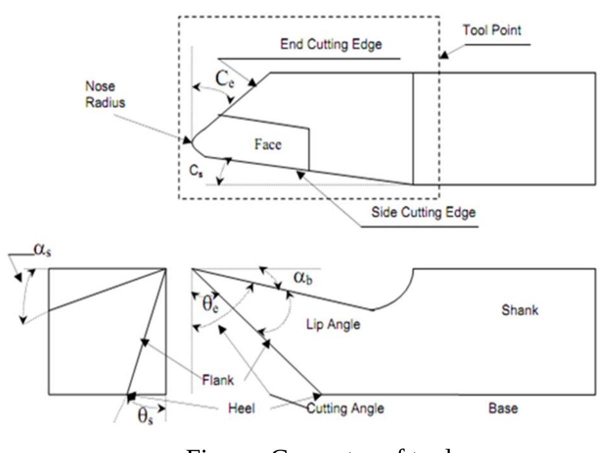

Figure: Geometry of tool

A. Design of Experiments

Designed experiments are often carried out in four phases: planning, screening (also called process characterization), optimization, and verification

1) Design of Experiments in Coded form

Expt NO	S.Speed(rpm)	Feed(mm/rev)	Depth of cut(mm)
1	+1	-1	-1
2	0	+1	+1
3	+1	0	-1
4	+1	0	0
5	-1	0	+1
6	+1	0	-1
7	-1	-1	-1
8	+1	+1	-1
9	0	0	+1
10	-1	+1	-1
11	-1	0	0
12	0	-1	0
13	+1	+1	0
14	-1	0	-1
15	0	-1	+1
16	-1	+1	+1
17	-1	0	+1
18	-1	+1	0
19	0	+1	0
20	0	+1	-1
21	+1	+1	+1
22	0	0	0
23	+1	-1	+1
24	-1	-1	0
25	0	-1	-1
26	+1	-1	0
27	-1	-1	+1

Table1 : Design of Experiments in coded form

II. EXPERIMENTAL SETUP AND MACHINING

The project was done in 3 stages.

1) Design of experiments was done using full factorial method.
2) Cycle time was calculated by machining the work piece on CNC Lathe Machine.
3) Analysis of results was done using MINITAB 17.1.30.

A. Selection of process variables

1) A total of three process variables and 3 levels are selected for the experimental procedure.
2) The deciding process variables are
a) Speed
b) Since it is a three level design by observing the parameters taken iFeed
c) Depth of cut
3) Speed of the spindle, i.e. the speed at which the spindle rotates the tool.
4) Feed is the rate at which the material is removed from the work piece.
5) Depth of cut is the depth up to which the tool is emerged in one cycle.
6) Selection of levels:
7) n various projects the levels of the factors are designed as follows

FACTORS	LEVEL1	LEVEL2	LEVEL3
S.SPEED(RPM)	75	115	190
FEED(MM/REV)	0.5	0.75	1
D.O.C(MM)	0.5	0.75	1

Table2 : Selection of process variables

B. Design of Experiments

Design of experiments was done using full factorial method.

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.

C. Selection of material

By studying various projects Aluminium is selected for machining operation. The composition of Aluminium is:

Silicon – 0.25%

Fe –0.40%

Copper – 0.05%

Manganese - 0.05%

Magnesium – 0.05%

Vanadium – 0.05%

Aluminium – Remaining

The dimensions of the workpiece used are length 300mm*50mmdia

Material Removal Rate

The material removal rate of the work piece is calculated by the formula given by

$$MRR=\frac{\prod (D^{2}-d^{2}) * f * N}{4}$$

D is the diameter of work piece before machining

d is the diameter of work piece after machining

f is feed in mm/rev

N is Spindle speed in rpm

The material removal rate is measured in the units of The material removal rate values are calculated and tabulated.

III. ANALYSIS OF VARIANCE (ANOVA) USING MINITAB

Steps involved in Factorial method for the determination of ANOVA

1) *Step 1*: Create design using General factorial method

Stat – DOE – Factorial – Create Factorial design

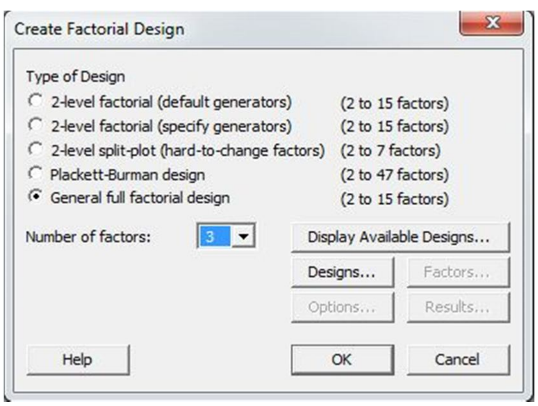

Figure 2 : Factorial design model

2) *Step 2*: Define Response Surface Design by selecting Speed, Feed, and Depth of cut as Input parameters.

Stat – DOE – Factorial – Define Response Surface Design

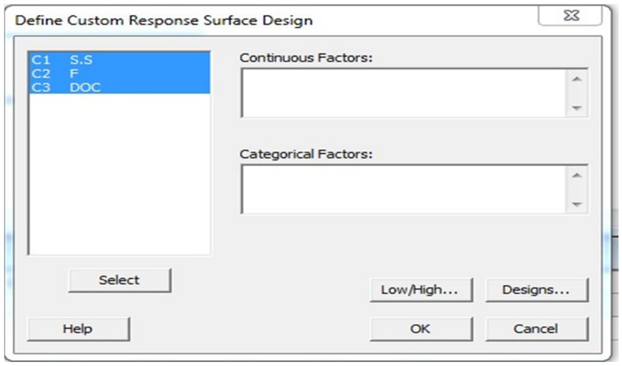

Figure 3 : Custom Response Surface Design

3) *Step 3*: Analyse the Custom Response design

Stat – DOE – Response Surface – Analyse Response Design

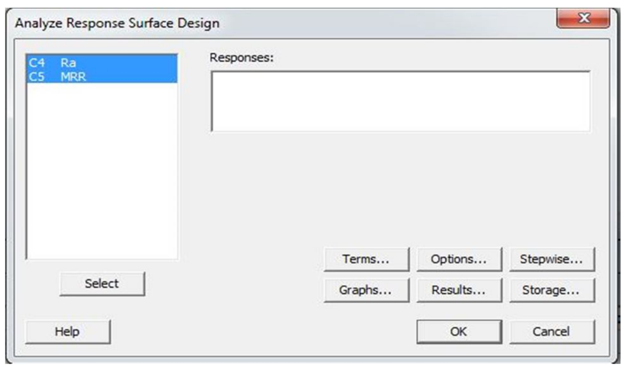

Figure 4 : Analyse Response Surface Design

IV. RESULTS AND DISCUSSIONS

Development of Mathematical Models

$Y = \beta + \beta 1\ x1 + \beta 2\ x2 + \ldots.\_\ \beta x\ xx + \in$

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

$Y = \beta 0 + \sum_{i=1}^{k} \beta_o x_o + \sum_{i=1}^{k} \beta ii\ \ xi2\ \ + \sum\ \ \ \sum_{i<j} \beta ij\ xixj\ + €$

Estimated coefficients generated in Minitab are as follows:

Term	Coefficient
Constant	-0.366
Speed	0.0003646
Feed	-0.172
Depth of cut	0.555
S.S*S.S	0.0000
F*F	30.17
D.O.C*D.O.C	-0.1972
S.S*F	-0.0011113
S.S*D.O.C	-0.000125
F*DOC	-0.058

Table3: Estimated coefficients for Ra using Minitab

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
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Equation generated for surface roughness is

Ra = -0.366 + 0.000346 S.S - 0.172 F + 0.555 DOC - 0.000000 S.S*S.S + 30.17 F*F - 0.1972 DOC*DOC - 0.001113 S.S*F - 0.000125 S.S*DOC - 0.058 F*DOC

R-Sq=98.97% R-Sq(Pred)=97.02%

Estimated coefficients generated in Minitab are as follows:

Term	Coefficient
Constant	10051
S.S	-6.77
F	-27608
DOC	-19162
S.S * S.S	.000762
F * F	-208542
DOC * DOC	1135
S.S * Feed	31.73
S.S * DOC	7.527
F * DOC	158863

Table 4: Estimated coefficients for MRR in Minitab

The Equation generated for material removal rate is given by

R-Sq=98.92% R-Sq (Pred)=96.53%

A. Graphs Obtained

A main effect occurs when the mean response changes across the levels of a factor main effect plots are used to compare the relative strength of the effects across factors.

S. No	Speed	Feed	Doc	MRR	Fx	Fy	Temp
1	75	0.5	0.5	0.01705653	8	23	30.6
2	75	0.5	0.75	0.021929825	10	27	31.2
3	75	0.5	1	0.029239766	15	32	31.2
4	75	0.75	0.5	0.027580772	18	45	31.5
5	75	0.75	0.75	0.031520883	15	42	30.8
6	75	0.75	1	0.047281324	23	55	31.4
7	75	1	0.5	0.024366472	11	35	31.6
8	75	1	0.75	0.043859649	19	64	31.6
9	75	1	1	0.058479532	34	78	34.6
10	115	0.5	0.5	0.025925926	9	20	30.06
11	115	0.5	0.75	0.0330033	13	28	31.8
12	115	0.5	1	0.0440044	17	49	31.8
13	115	0.75	0.5	0.040509259	26	50	31.2
14	115	0.75	0.75	0.052083333	17	53	32.6
15	115	0.75	1	0.070546737	29	70	32.2
16	115	1	0.5	0.036310821	15	52	31.2
17	115	1	0.75	0.058097313	20	69	32.6
18	115	1	1	0.087145969	36	83	34.6
19	190	0.5	0.5	0.047789725	13	26	31.4
20	190	0.5	0.75	0.048387097	14	33	31.8
21	190	0.5	1	0.077658303	22	50	31.8
22	190	0.75	0.5	0.058479532	14	45	31.6
23	190	0.75	0.75	0.087719298	21	40	32.2
24	190	0.75	1	0.116959064	24	65	32.6
25	190	1	0.5	0.069444444	14	43	32.1
26	190	1	0.75	0.09557945	16	51	32.6
27	190	1	1	0.131421744	30	82	34.6

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B. DRY Condition Results

1) Response Surface Regression: MRR versus Speed, Feed, Doc

Analysis of Variance for MRR

Term	Coef	SE Coef	T	P
Constant	0.058843	0.002043	28.801	0.000
Speed	0.024007	0.000894	26.843	0.000
Feed	0.014974	0.000901	16.619	0.000
Doc	0.018222	0.000901	20.224	0.000
Speed*Speed	0.000489	0.001733	0.282	0.781
Feed*Feed	-0.006426	0.001549	-4.148	0.001
Doc*Doc	0.003658	0.001549	2.361	0.030
Speed*Feed	0.005380	0.001079	4.987	0.000
Speed*Doc	0.006968	0.001079	6.459	0.000
Feed*Doc	0.007233	0.001095	6.603	0.000

S = 0.00379440 PRESS = 0.000656223

R-Sq = 98.90% R-Sq(pred) = 97.04% R-Sq(adj) = 98.31%

2) Estimated Regression Coefficients for MRR Using Data in Uncoded Units

Term	Coef
Constant	0.0320761
Speed	-2.65896E-04
Feed	0.0777274
Doc	-0.165920
Speed*Speed	1.47839E-07
Feed*Feed	-0.102809
Doc*Doc	0.0585245
Speed*Feed	0.000374245
Speed*Doc	0.000484728
Feed*Doc	0.115727

MRR = 0.0321 - 0.000266 Speed + 0.0777 Feed - 0.1659 Doc + 0.000000 Speed*Speed
- 0.1028 Feed*Feed + 0.0585 Doc*Doc + 0.000374 Speed*Feed + 0.000485 Speed*Doc + 0.1157 Feed*Doc

C. Response Surface Regression: Fx versus Speed, Feed, Doc

1) Analysis of Variance for Fx

Term	Coef	SECoef	T	P
Constant	20.3752	1.7974	11.336	0.000
Speed	0.8333	0.7868	1.059	0.304
Feed	3.9288	0.7927	4.957	0.000
Doc	5.6717	0.7927	7.155	0.000
Speed*Speed	-2.9123	1.5249	-1.910	0.073
Feed*Feed	-3.2222	1.3628	-2.364	0.030
Doc*Doc	3.7778	1.3628	2.772	0.013
Speed*Feed	-1.7972	0.9491	-1.894	0.075
Speed*Doc	0.0492	0.9491	0.052	0.959
Feed*Doc	3.0000	0.9636	3.113	0.006

S = 3.33804 PRESS = 447.751

R-Sq = 86.61% R-Sq(pred) = 68.34% R-Sq(adj) = 79.52%

2) Estimated Regression Coefficients for Fx using data in uncoded units

Term	Coef
Constant	-5.89434
Speed	0.339113
Feed	73.6137
Doc	-104.434
Speed*Speed	-8.80837E-04
Feed*Feed	-51.5556
Doc*Doc	60.4444
Speed*Feed	-0.125020
Speed*Doc	0.00342298
Feed*Doc	48.0000

Fx = -5.9 + 0.339 Speed + 73.6 Feed - 104.4 Doc - 0.000881 Speed*Speed - 51.6 Feed*Feed + 60.4 Doc*Doc - 0.1250 Speed*Feed + 0.0034 Speed*Doc + 48.0 Feed*Doc

D. Response Surface Regression: Fy versus Speed, Feed, Doc

1) Analysis of Variance for Fy

Term	Coef	SECoef	T	P
Constant	53.787	3.284	16.380	0.000
Speed	1.889	1.437	1.314	0.206
Feed	14.672	1.448	10.131	0.000
Doc	12.660	1.448	8.742	0.000
Speed*Speed	-7.491	2.786	-2.689	0.016
Feed*Feed	-4.722	2.490	-1.897	0.075
Doc*Doc	4.944	2.490	1.986	0.063
Speed*Feed	-2.690	1.734	-1.551	0.139
Speed*Doc	1.575	1.734	0.908	0.377
Feed*Doc	4.250	1.760	2.414	0.027

S = 6.09850 PRESS = 1633.58

R-Sq = 92.45% R-Sq(pred) = 80.50% R-Sq(adj) = 88.46%

2) Estimated Regression Coefficients for Fy using data in uncoded units

Term	Coef
Constant	-39.7967
Speed	0.691452
Feed	145.813
Doc	-133.541
Speed*Speed	-0.00226570
Feed*Feed	-75.5556
Doc*Doc	79.1111
Speed*Feed	-0.187123
Speed*Doc	0.109535
Feed*Doc	68.0000

Fy = -39.8 + 0.691 Speed + 145.8 Feed - 133.5 Doc - 0.002266 Speed*Speed - 75.6 Feed*Feed + 79.1 Doc*Doc - 0.187 Speed*Feed + 0.110 Speed*Doc + 68.0 Feed*Doc

E. Response Surface Regression: Temp versus Speed, Feed, Doc

1) Analysis of Variance for Temp

Term	Coef	SECoef	T	P
Constant	31.8822	0.3317	96.107	0.000
Speed	0.3444	0.1452	2.372	0.030
Feed	0.7645	0.1463	5.225	0.000
Doc	0.7514	0.1463	5.136	0.000
Speed*Speed	-0.1719	0.2814	-0.611	0.550
Feed*Feed	0.2756	0.2515	1.096	0.289
Doc*Doc	0.0922	0.2515	0.367	0.718
Speed*Feed	-0.0435	0.1752	-0.249	0.807
Speed*Doc	-0.0077	0.1752	-0.044	0.966
Feed*Doc	0.5133	0.1779	2.886	0.010

S = 0.616091   PRESS = 15.2232

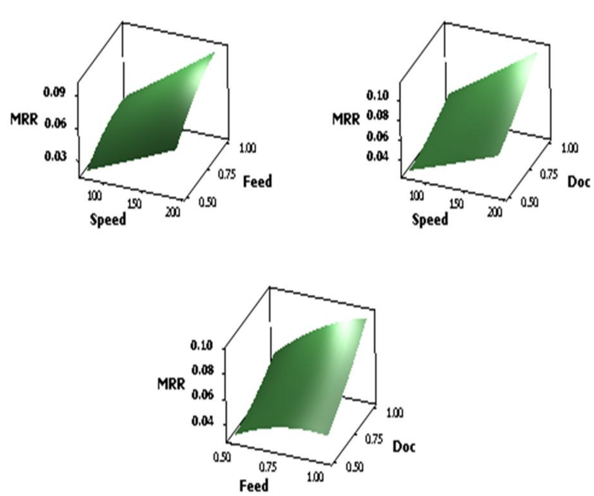
R-Sq = 80.52% R-Sq(pred) = 54.04% R-Sq(adj) = 70.21%

2) Estimated Regression Coefficients for Temp using data in Uncoded Units

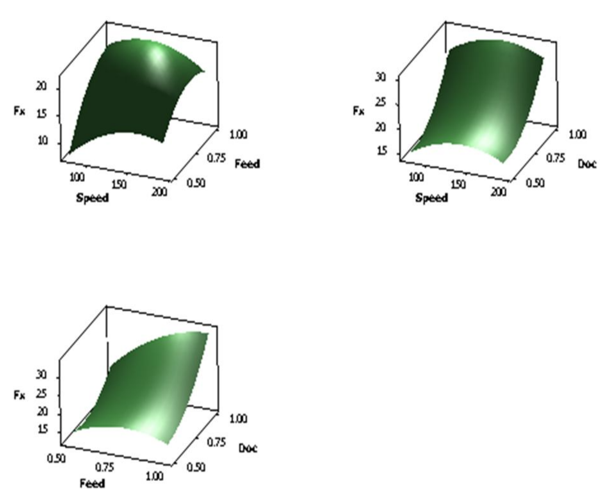
Term	Coef
Constant	33.2041
Speed	0.0224376
Feed	-9.31416
Doc	-5.29672
Speed*Speed	-5.19807E-05
Feed*Feed	4.40889
Doc*Doc	1.47556
Speed*Feed	-0.00302852
Speed*Doc	-5.34637E-04
Feed*Doc	8.21333

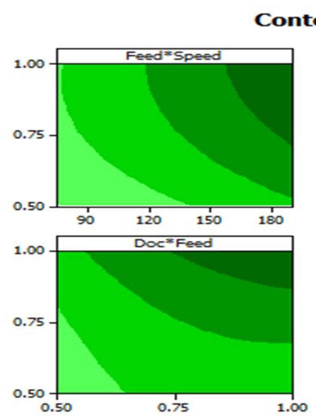
Temp = 33.20 + 0.0224 Speed - 9.31 Feed - 5.30 Doc - 0.000052 Speed*Speed + 4.41 Feed*Feed + 1.48 Doc*Doc - 0.0030 Speed*Feed - 0.0005 Speed*Doc + 8.21 Feed*Doc

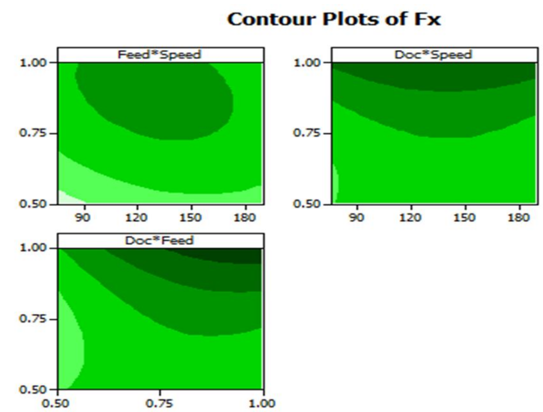
Surface Plots of MRR

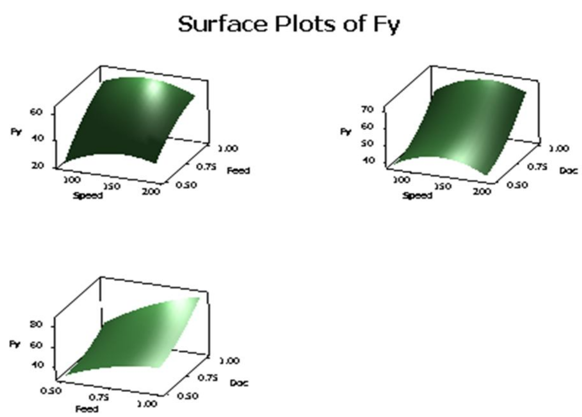


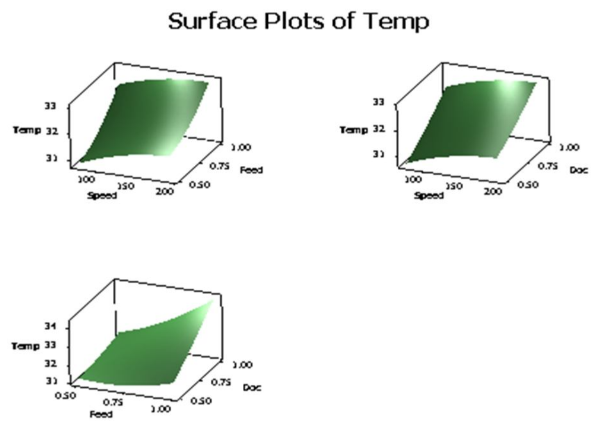
Surface Plots of Fx

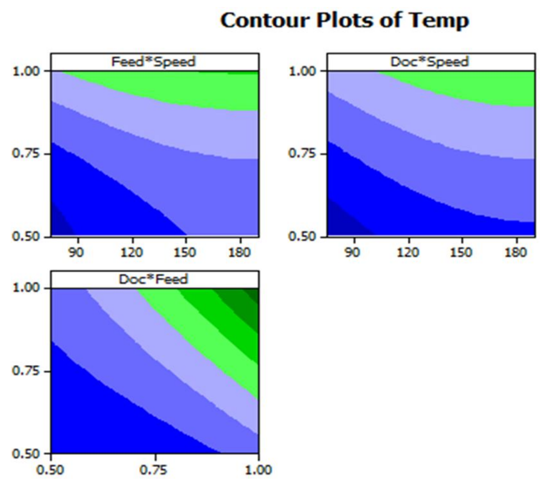












F. Multi response optimisation

1) Response Optimization

a) Parameters

	Goal	Lower	Target	Upper	Weight	Import
MRR	Maximum	0.017	0.095	0.095	1	1
Fx	Minimum	25.000	25.000	30.000	1	1
Fy	Maximum	40.000	65.000	65.000	1	1
Temp	Minimum	32.000	32.000	34.500	1	1

b) Starting Point

Speed = 75
Feed = 0.5
Doc = 0.5

c) Global Solution

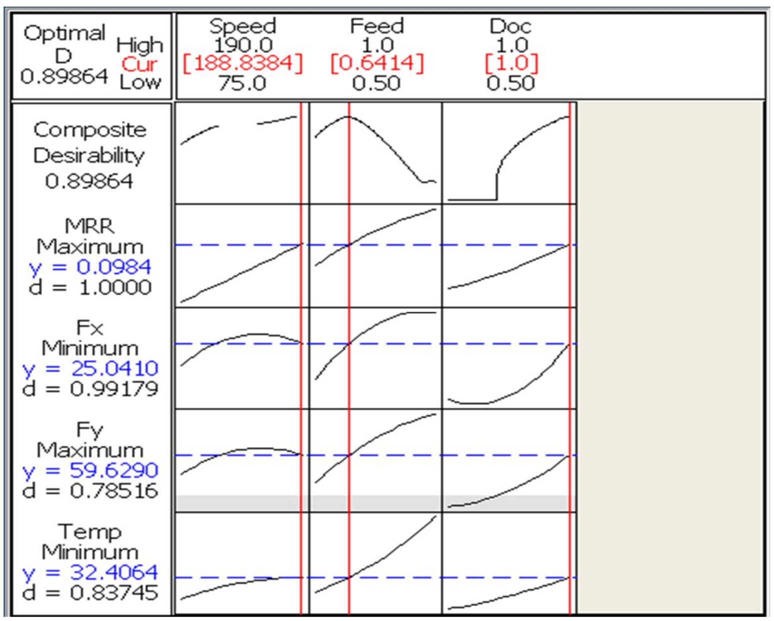
Speed = 188.838
Feed = 0.641414
Doc = 1

d) Predicted Responses

MRR = 0.0984 , desirability = 1.000000
Fx = 25.0410 , desirability = 0.991791
Fy = 59.6290 , desirability = 0.785160
Temp = 32.4064 , desirability = 0.837452
Composite Desirability = 0.898637

G. Response

1) Response Optimizer



Stat > DOE > Response Surface > Response Optimizer

Use response optimization to help identify the combination of input variable settings that jointly optimize a single response or a set of responses. Joint optimization must satisfy the requirements for 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.

The optimization plot as shown signifies the affect 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 maximum material removal rate.

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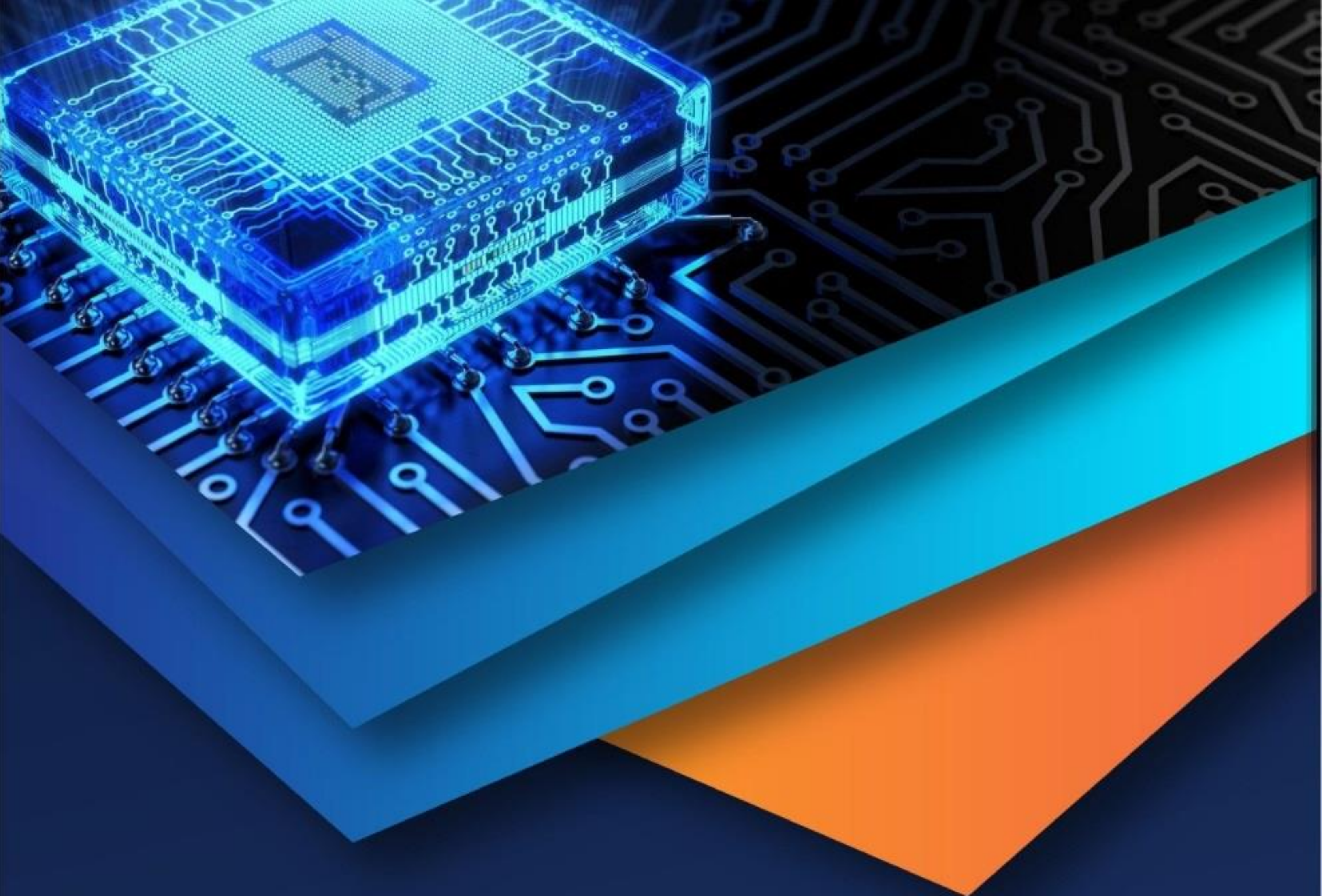

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