

# MULTI – OBJECTIVE OPTIMIZATION OF MACHINING PARAMETERS OF EN36 STEEL USING RSM

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## Abstract

This paper reports on the optimization of turning process on all geared lathe by the effects of machining parameters applying Response Surface Methodology (RSM) to improve the quality of manufactured goods, and engineering development of designs for studying variations. EN36 is used as the work piece material and TNMG insert is used as a tool for carrying out the experimentation to optimize the Temperature, and Surface Roughness. There are three machining parameters i.e. Spindle speed, Feed rate, Depth of cut. Twenty Seven experiments are done by varying all the parameters. Regression equations are generated from RSM. Their functional relationship and effect on different parameters is studied. ANOVA is applied to know which input parameter has most significant effect on temperature and surface roughness. It is observed that as the spindle speed and depth of cut decreases the temperature decreases. The surface roughness is minimum when the spindle speed is high and feed is less. Optimum value of each parameter will be obtained by using Minitab16 Software.

**Keywords:** EN 36, RSM, TNMG, Surface roughness, ANOVA.

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## 1. INTRODUCTION

All machining processes remove material to form shapes. As metals are still the most widely used materials in manufacturing, machining processes are usually used for metals. However, machining can also be used to shape plastics and other materials which are becoming more widespread. Basically all the different forms of machining involve removing material from a component using a rotating cutter. The differences between the various types arise from the relative motion between cutting tool and work piece and the type of cutting tool used. Typically machining will be done using a machine tool. This tool holds the work piece and the rotating cutting tool and allows relative movement between the two. Usually machine tools are dedicated to one type of machining operation, although some more flexible tools allow more than one type of machining to be performed.

The machine tool can either be under manual or automatic control. Automatic control is more expensive because of the need to invest in the necessary control mechanisms however it becomes more desirable as the number of components produced increases and labour costs can be reduced. The speed at which a machine tool can process individual components is a function of the cutting speed of the tool and the downtime involved in changing the work piece and maintaining the tool (this will usually involve changing the cutting edges of the tool). Some very flexible tools allow automatic changing of components and cutting tools, however they greatly add to initial purchase price of the machine tool. The cutting speed of the tool is usually dictated by the type of material being machined, in general

the harder the material, the slower the machining time. Machining speed can be increased by increasing the rotational speed of the cutter; however this will be at the expense of the tool life. Hence for machining processes there is an optimum cutting speed that balances tooling costs with cutting speed.

It is important to view machining, as well as all manufacturing operations, as a system consisting of the work piece, the tool and the machine.

### 1.1 Nomenclatures

D	Depth of cut
F	Feed
S	Speed
T	Temperature
SR	Surface Roughness

## 2. EXPERIMENTAL SETUP

### 2.1 Workpiece Material

EN36 steel is used as the work piece material for carrying out the experimentation to optimization of cutting parameters. The bars used are of diameter 25 mm and length 100 mm. The turning process is done over a length of 50mm. The chemical composition and mechanical properties of EN36 is shown in table 2.1 and 2.2.

**Table 2.1:** Chemical Composition

S.NO	METAL	COMPOSITION BY WEIGHT IN (%)
1	Carbon	0.14
2	Silicon	0.19
3	Manganese	0.46
4	Sulphur	0.009
5	Phosphorous	0.006
6	Nickel	3.55
7	Chromium	1.11
8	Molybdenum	0.12

**Table 2.2:** Mechanical Properties

Section mm	Yield Strength Mpa	Tensile Strength Mpa	Elongation (%)	Impact Izod J	Hardness HB
25	950	1150	15	45	340

**Typical applications:** EN36 steel has wide applications. It is used in disc wheels, grooved shaft, cams, gears, and heavy duty gears for air craft's, heavy vehicles, universal joints and auto mobile transmission parts.

### 2.2 All Geared Lathe

These machines are known for their sturdy construction, high performance and noiseless operation. The following are the specifications of the lathe. This table will give the ranges of the speed, feed, and depth of cut of the lathe machine that are possible to set.

Swing over the bed = 310mm  
 Length of bed = 1530mm  
 No. of speeds = 18

**Table 2.3:** Feeds available

	SII		SI		SII		SI	
	L	H	L	H	L	H	L	H
E 2	1.29	0.27	0.64	0.31	0.32	0.06	0.16	0.03
E 3	1.14	0.24	0.57	0.13	0.28	0.06	0.14	0.03
A 2	1.03	0.22	0.51	0.11	0.25	0.05	0.12	0.02
E 4	0.92	0.19	0.46	0.09	0.23	0.04	0.11	0.02
E 1	0.82	0.18	0.41	0.09	0.20	0.04	0.10	0.02
C 3	0.73	0.15	0.36	0.07	0.18	0.03	0.09	0.02
C 4	0.66	0.14	0.33	0.07	0.16	0.03	0.08	0.01
A 5	0.63	0.13	0.31	0.06	0.51	0.03	0.07	0.01
D 5	0.52	0.11	0.26	0.05	0.13	0.02	0.06	0.01
B 5	0.42	0.09	0.21	0.04	0.10	0.02	0.05	0.01

In the above table,  
 L = longitudinal feed and  
 H = horizontal feed.

The values of first four lines are the feed that are possible with the gear combination 48-127-24. The remaining four lines are the feed that are possible with the gear combination 24-120-48.

**Table 2.4:** Speeds available

		1	2	3
I	A	360	1810	1095
	B	100	500	300
	C	280	1400	840
		1	2	3
II	A	235	1200	700
	B	65	330	200
	C	160	910	550



**Fig. 2.1:** All Geared lathe

### 2.3 Cutting Tool Used

The tool is single point cutting tool made of Tungsten Carbide. This insert is triangle shaped with three cutting edges on either side.



**Fig. 2.2:** TNGM Insert

## 2.4 Experimental Design with Three Level Factors

The nonlinear relationship among the process parameters, if it exists, can only be revealed if more than two levels of the parameters are considered. Thus each selected parameter was analyzed at three levels. The process parameters and their values at three levels are given in table 2.5.

**Table 2.5:** Parameter levels

Levels	Depth of cut (mm)	Feed rate (mm/rev)	Spindle speed (rpm)
1	0.3	0.105	400
2	0.6	0.158	800
3	0.9	0.205	1200

## 2.5 Historical Data

The historical values of depth of cut, feed, speed, temperature and surface roughness are shown in table 2.6.

**Table 2.6:** Historical data in measuring Temperature and Surface Roughness

S.No.	Depth of cut (mm)	Feed rate (mm/Rev)	Spindle Speed (rpm)	Temperature (°C)	Surface Roughness (µm)
1	0.3	0.105	400	32.35	7.66
2	0.3	0.105	800	35	7.93
3	0.3	0.105	1200	33.5	7.33
4	0.3	0.158	400	35.5	15.18
5	0.3	0.158	800	34	15.09
6	0.3	0.158	1200	32.5	16.02
7	0.3	0.205	400	33.5	31.53
8	0.3	0.205	800	35.35	30.44
9	0.3	0.205	1200	32.75	30.21
10	0.6	0.105	400	36.25	8.98
11	0.6	0.105	800	34.5	7.72
12	0.6	0.105	1200	45	7.58
13	0.6	0.158	400	38.25	17.30
14	0.6	0.158	800	36.5	16.26
15	0.6	0.158	1200	33.75	17.81
16	0.6	0.205	400	36.05	31.22
17	0.6	0.205	800	37.35	32.29
18	0.6	0.205	1200	36.5	31.64
19	0.9	0.105	400	35.75	10.51
20	0.9	0.105	800	35.25	8.85
21	0.9	0.105	1200	39	12.05
22	0.9	0.158	400	35.5	15.53
23	0.9	0.158	800	44.5	16.17
24	0.9	0.158	1200	37.5	16.94
25	0.9	0.205	400	35.5	31.17
26	0.9	0.205	800	39	30.76
27	0.9	0.205	1200	34.75	32.12

## 3. RESULTS

The analysis is made using the Minitab 16 software. The effect of feed, spindle speed and depth of cut and there interaction on the temperature and surface quality (roughness) has been developed using multiple regression model. The analysis of variance (ANOVA) was applied to study the effect of the input parameters on the surface roughness and temperature.

Table 3.1 gives the Estimated Regression Coefficients of temperature for uncoded units. The value “p” for the model is less than 0.05 which indicates that the model terms are significant, which is desirable as it indicates that the terms in the model have a significant effect on the response.

**Table 3.1:** Estimated Regression Coefficients for T

Term	Coef	SE Coef	T	P
Constant	10.531	0.8571	12.287	0.000
D	4.587	1.1061	4.147	0.001
F	200.549	9.0198	22.234	0.000
S	0.012	0.0008	14.270	0.000
D×D	-0.617	0.7656	-0.806	0.431
F×F	-611.089	27.6762	-22.080	0.000
S×S	-0.000	0.0000	-0.806	0.431
D×F	-5.660	3.2460	-1.744	0.099
D×S	0.001	0.0004	1.710	0.105
F×S	0.004	0.0024	1.744	0.099

S = 0.168770 PRESS = 1.65827  
R-Sq = 99.90% R-Sq(pred)= 99.66%  
R-Sq(adj) = 99.85%

The regression equations generated for temperature is as follows

$$T = 10.531 + 4.587 \times D + 200.549 \times F + 0.012 \times S - 0.617 \times D^2 - 611.089 \times F^2 - 5.66 \times D \times F + 0.001 \times D \times S + 0.004 \times F \times S \quad (3.1)$$

From Response surface Eq. (3.1), the most significant factor on the temperature is speed. The next contribution on temperature is depth of cut and feed. The ANOVA for temperature is shown in table 3.2

**Table 3.2:** Analysis of Variance for T

Source	D F	Seq SS	Adj SS	Adj MS	F	P
Regression	9	480.479	480.479	53.3865	1874.31	0.000
Linear	3	466.299	18.303	6.1009	214.19	0.000
D	1	20.056	0.490	0.4898	17.20	0.001
F	1	6.188	14.081	14.081	494.36	0.000
S	1	440.056	5.800	5.7999	203.63	0.000
Square	3	13.923	13.293	4.431	162.94	0.000
D×D	1	0.019	0.019	0.0185	0.65	0.431

F×F	1	13.886	13.886	13.886	487.5	0.000
S×S	1	0.019	0.019	0.0185	0.65	0.431
Interaction	3	0.257	0.257	0.0855	3.00	0.059
D×F	1	0.087	0.087	0.0866	3.04	0.099
D×S	1	0.083	0.083	0.0833	2.93	0.105
F×S	1	0.087	0.087	0.0866	3.04	0.099
Residual Error	17	0.484	0.484	0.0285		
Total	26	480.96				

F×F	1	114.56	114.56	114.56	309.87	0.000
S×S	1	1.45	1.45	1.450	3.92	0.064
Interaction	3	3.06	3.06	1.019	2.76	0.074
D×F	1	1.40	1.40	1.400	3.79	0.068
D×S	1	1.58	1.58	1.577	4.27	0.054
F×S	1	0.08	0.08	0.080	0.22	0.647
Residual Error	17	6.29	6.29	0.370		
Total	26	2406.63				

Table 3.3 gives the Estimated Regression Coefficients of surface roughness for uncoded units. The value “p” for the model is less than 0.05 which indicates that the model terms are significant, which is desirable as it indicates that the terms in the model have a significant effect on the response.

**Table 3.3:** Estimated Regression Coefficients for SR

Term	Coef	SE Coef	T	P
Constant	19.31	3.0881	6.253	0.000
D	11.92	3.9850	2.991	0.008
F	-300.88	32.4962	-9.259	0.000
S	-0.01	0.0030	-1.855	0.081
D×D	-7.43	2.7581	-2.692	0.015
F×F	1755.23	99.7107	17.603	0.000
S×S	0.00	0.0000	1.981	0.064
D×F	-22.76	11.6947	-1.946	0.068
D×S	0.00	0.0015	2.065	0.054
F×S	-0.00	0.0088	-0.466	0.647

S = 0.608038 PRESS = 15.1617  
 R-Sq = 99.74% R-Sq(pred) = 99.37%  
 R-Sq(adj) = 99.60%

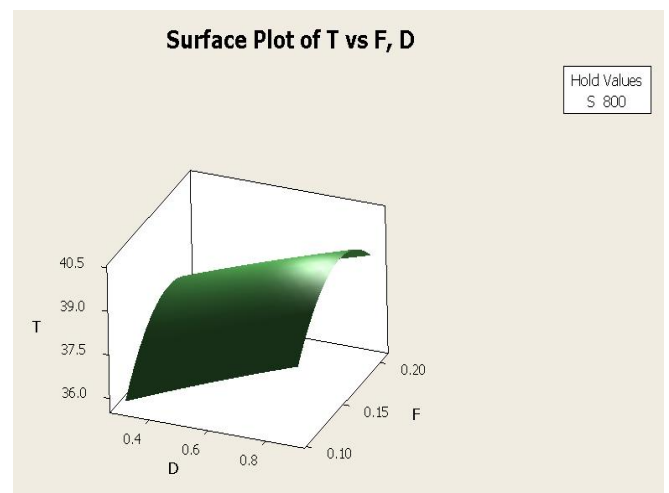
$$SR = 19.31 + 11.92 \times D - 300.88 \times F - 0.01 \times S - 7.43 \times D^2 + 1755.23 \times F^2 - 22.76 \times D \times F \quad (3.2)$$

From response surface Eq. (3.2), the most significant factor on the surface roughness is feed. The next contribution on surface roughness is depth of cut and speed. The ANOVA for surface roughness is shown in table 3.4

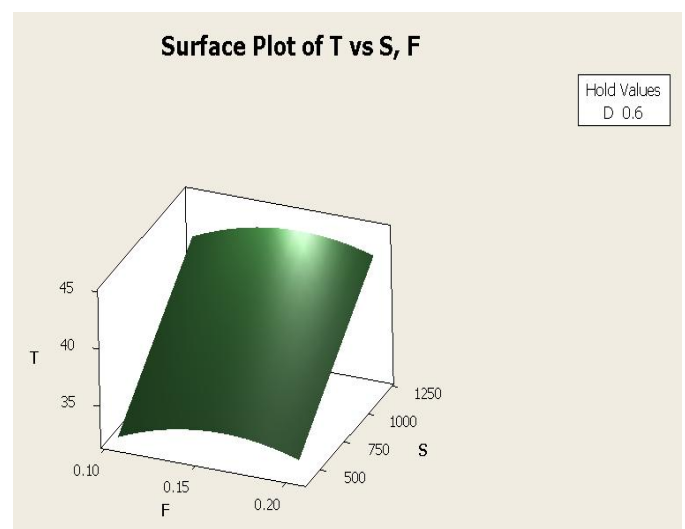
**Table 3.4:** Analysis of Variance for SR

Source	D F	Seq SS	Adj SS	Adj MS	F	P
Regression	9	2400.34	2400.34	266.705	721.39	0.000
Linear	3	2278.59	37.97	12.657	34.24	0.000
D	1	5.70	3.31	3.308	8.95	0.008
F	1	2272.03	31.69	31.695	85.73	0.000
S	1	0.86	1.27	1.273	3.44	0.081
Square	3	118.69	118.69	39.564	107.01	0.000
D×D	1	2.68	2.68	2.680	7.25	0.015

RSM also generates the surface plots having influence of input variables on output along with the interactions of input variables on the selected output parameter.



**Fig. 3.1:** Surface Plot of T vs F, D



**Fig. 3.2:** Surface Plot of T vs S, F

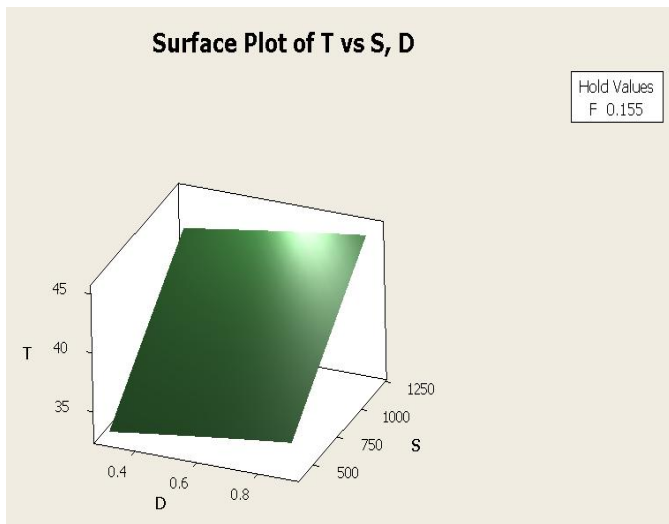


Fig. 3.3: Surface Plot of T vs S, D

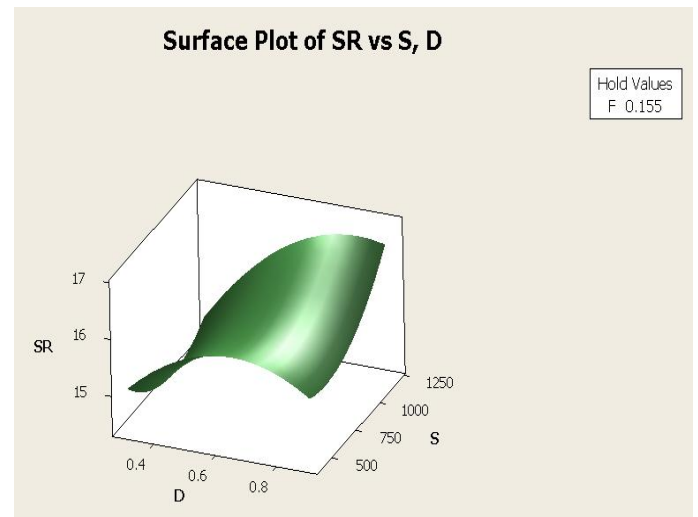


Fig. 3.6: Surface Plot of SR vs S, D

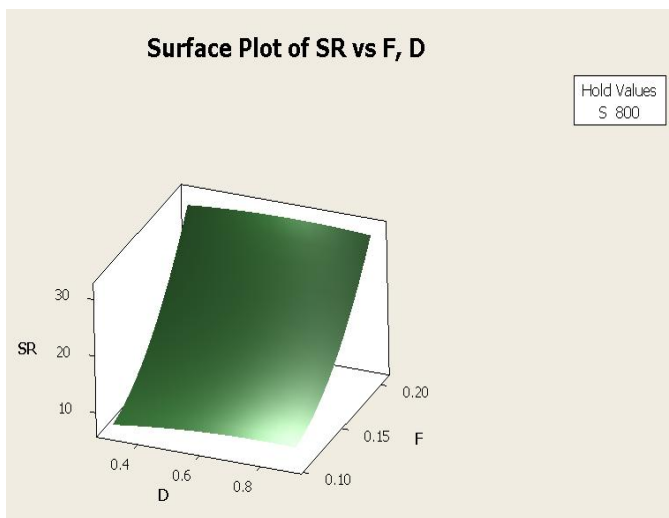


Fig. 3.4: Surface Plot of SR vs F, D

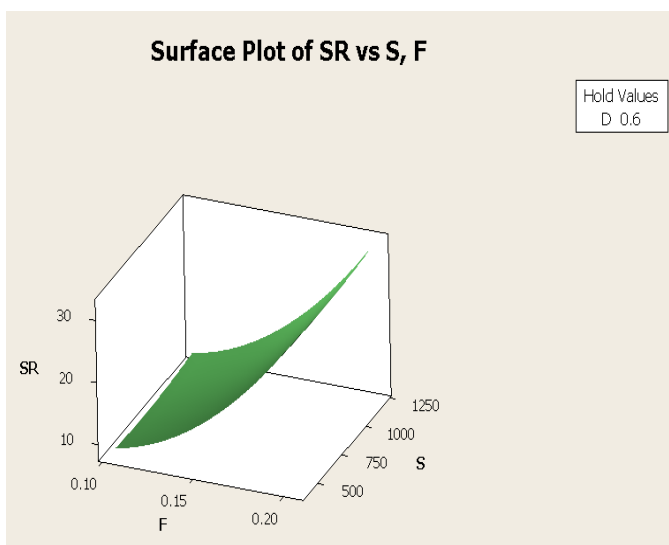


Fig. 3.5: Surface Plot of SR vs S, F

To understand how the response changes in a given direction by adjusting the design variables response surface graphs are used. Fig. 3.1, 3.2, & 3.3 shows the surface plots of Temperature vs depth of cut & feed, feed & speed, depth of cut & speed. From these graphs it is observed that as the speed and depth of cut increases, the temperature increases. Fig. 3.4, 3.5 & 3.6 shows the surface plots of Surface Roughness vs depth of cut & feed, feed & speed, depth of cut & speed respectively. From these graphs it is observed that as the feed and speed increases, the surface roughness increases.

By using RSM the optimal values of temperature and surface roughness can be found. From fig. 3.7 the optimal values are

- Dept of cut = 0.3 mm
- Feed = 0.105 mm/rev
- Speed = 400 rpm

Optimal	D	F	S
D	0.90	0.2050	1200.0
High	[0.30]	[0.1050]	[400.0]
Low	0.30	0.1050	400.0
Composite Desirability	0.99198		
T	Minimum		
	y = 30.9352		
	d = 1.0000		
SR	Minimum		
	y = 7.7242		
	d = 0.98402		

Fig. 3.7: Optimal Values.

#### 4. CONCLUSION

The current study was done to study the effect of machining parameters on the temperature and surface roughness. A mathematical equation has been generated between input parameters and response. The following conclusions are drawn from the study:

1. The temperature is mainly affected by depth of cut and cutting speed
2. The surface roughness is mainly affected by feed, depth of cut and speed.

The parameters taken in the experiments are optimized to obtain the minimum temperature and surface roughness. The optimum setting of cutting parameters are:

Dept of cut	= 0.3 mm
Feed	= 0.105 mm/rev
Speed	= 400 rpm

#### FUTURE SCOPE

The turning process is performed in dry condition. The experiment may be conducted in future by measuring tool wear and material removal rate. The optimal cutting parameters for minimum tool wear and minimum surface roughness and maximum material removal rate can be found out.

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