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Optimization of Machining Parameters of 20MnCr5 Steel in Turning Operation using Taguchi technique

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Abstract: *Now-a-days increasing the productivity and the quality of the machined parts are the main challenges of metal cutting industry during turning processes. Optimization methods in turning processes, considered being a vital role for continual improvement of output quality in product and processes include modeling of input-output and in process parameters relationship and determination of optimal cutting conditions. This paper present on Experimental study to optimize the effects of cutting Parameters on Surface finish and MRR of 20MnCr5 Steel alloy work material by employing Taguchi techniques. The orthogonal array, signal to noise ratio and analysis of variance were employed to study the performance characteristics in turning operation. Five parameters were chosen as process variables: Cutting Speed, Feed, Depth of cut, Hardness of cutting Tool, Cutting environment (wet and dry). The experimentation plan is designed using Taguchi's L9 Orthogonal Array (OA) and Minitab statistical software is used. Optimal cutting parameters for minimum surface roughness (SR) and maximum material removal rate were obtained. Finally, the relationship between factors and the performance measures were developed by using multiple regression analysis.*

Keywords: *orthogonal array, surface roughness, MINITAB, regression model, turning, coolant*

I. Introduction

In this work, the Taguchi methods, a powerful statistical tool to design of experiments for quality, is used to find the optimal cutting parameters for turning operations. Even though the present not only optimize cutting parameters for turning operations but also the main cutting parameters and its interaction that affect the cutting performance is the highlight of the work. Experimental results are provided to confirm the effectiveness of Taguchi's approach. Every manufacturing industry aims at producing a large number of products within relatively lesser time. But it is felt that reduction in manufacturing time may cause severe quality loss. In order to embrace these two conflicting criteria it is necessary to check quality level of the item either on-line or off-line. The purpose is to check whether quality lies within desired tolerance level which can be accepted by the customers. Quality of a product can be described by various quality attributes. The attributes may be quantitative or qualitative. If quality falls down the expected level the controller supplies a feed back in order to reset the process environment. In off-line quality control the method is either to check the quality of few products from a batch or lot (acceptance sampling) or to evaluate the best process environment capable of producing desired quality product. This invites a optimization problem which seeks identification of the best process condition or parametric combination for the said manufacturing process. If the problem is related to a single quality attribute then it is called single objective or single response optimization.

II. Literature Review

Machining parameters in metal turning are cutting speed, feed and depth of cut. The setting of these parameters determines the quality characteristics of turned parts. Consideration of machining parameter optimization started out as early as 1907 when (Taylor, 1907) [1] acknowledged the existence of an optimum cutting speed for maximizing material removal rate in single pass turning operations. Research on machining parameter optimization has increased since the 1950's.

In 1950 (Gilbert, 1950) [2] presented a theoretical analysis of optimization of machining process and proposed an analytical procedure to determine the cutting speed for a single pass turning operation with fixed feed rate and depth of cut by using two different objectives maximum production rate and minimum machining cost.

P. G. Benardos and G. C. Vosniakos, [3] this paper presents the set of parameters that are influence the surface Roughness and also they diagrammatically displayed in Fishbone Diagram.

Aman Aggarwal and Hari Singh, [4] this paper presents that Fuzzy Logic, Genetic Algorithm, scatter search and Taguchi technique are the latest optimization Techniques.

Mahendra Korat and Neeraj Agarwal (2012) [5] investigated the effects of the process parameters viz., coolant condition, cutting speed, feed, depth of cut, nose radius, on response characteristics viz., material removal rate, surface roughness, on EN24 material in CNC turning. ANOVA results shows that nose radius, feed rate, depth of cut, cutting speed and coolant condition affects the surface roughness by 65.38%, 25.15%, 3.06%, 1.41% and 0.09% respectively.

Sahoo et al. (2008) [9] studied for optimization of machining parameters combinations emphasizing on fractal characteristics of surface profile generated in CNC turning operation. The authors used L27 Taguchi Orthogonal Array design with machining parameters: speed, feed and depth of cut on three different work piece materials viz., aluminum, mild steel and brass. It was concluded that feed rate was more significant influencing surface finish in all three materials.

III. TAGUCHI TECHNIQUE

The Taguchi experimental design method, by Genichi Taguchi is a well-known, unique and powerful technique for product or process quality improvement. It is widely used for analysis of experiment and product or process optimization. Genichi Taguchi is a Japanese engineer who has been active in the improvement of Japan's industrial products and processes since the late 1940s.

Taguchi introduces his concepts to:

• Quality should be designed into a product and not inspected into it.

• Quality is best achieved by minimizing the deviation from a target.

• Cost of quality should be measured as a function of deviation from the standard and the losses should be measured system wide.

IV. EXPERIMENTAL DETAILS

4. 1: Material

20MnCr5 is categorized as case hardened steel produced by casting, it is easily machinable and can have a wide variety of surface finishes. It also has high strength and stiffness. It is used in the field of high stressed components in automobile industry like small gear, shafts, crankshafts, connecting rods, cam shafts, piston bolts, spindles and other mechanical controlling parts.

Carbon	0.220%
Manganese	1.112%
Silicon	0.244%
Sulphur	0.026%
Phosphorus	0.028%
Chromium	1.154%

Table 1: Chemical compositon of 20MnCr5

4. 2: Cutting tool inserts

Inserts are individual cutting tools with several cutting points. Inserts are usually clamped on the tool shank with various locking mechanisms. Most of high performance cutting tools use the insert method. Here there are three type cutting insrets are using they are

1. SUMITOMO AC700G – CARBIDE COATED
2. KORLOY PC9030 – PVD COATED STEEL GRADE
3. TAGUETEC CT3000 – CERAMIC UNCOATED

4. 3: Machine tool

Fig1: CNC Horizontal turning lathe LL 15T L3

4.4: Cutting parameters and their levels

Symbol	Cutting Parameter	Unit	Level 1	Level 2	Level 3
A	Cutting Speed	rpm	1000	2000	3000
B	Feed	mm/rev	0.05	0.1	0.15
C	Depth of Cut	mm	0.2	0.4	0.6
D	Hardness of Cutting Tool	HRC	65 (Ceramic Uncoated)	71 (PVD Coated Steel Grade)	76 (Carbide Coated)

Table 2 : Cutting parameters and their levels

4. 5: To find Minimum number of Experiments to be conducted

Parameter	Number of Levels	Degree of Freedom
Cutting Speed	3	2
Feed	3	2
Depth of Cut	3	2
Hardness of Cutting Tool	3	2
	Total Degrees of Freedom	8
	Minimum no. of Experiments	9

Table 3: Factors, levels and Degree of freedom

4. 6: Orthogonal array

Trial no.	Cutting Speed (m/min)	Feed (mm/rev)	Depth of Cut (mm)	Hardness of Cutting tool (HRC)
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 4: standard L9 orthogonal array

V. FORMULAS USED

1) MRR (a) represents Actual Material Removal Rate in mm3/min

$$\textbf{MRR (a)} = \frac{[\text{Initial Weight of wirkpiece (gm)} - \text{Final Weight of workpiece (gm)}\ ]}{\text{Density}(\text{gm/mm3}) \times \text{Machining Time (min)}}\ \textbf{mm3/min}$$

2) MRR (t) represents Theoretical Material Removal Rate in mm3/min

MRR (t) = f * d * v * 1000 mm3/min

Here 'f' denotes feed in mm/rev,'d' denotes depth of cut in mm and 'v' denotes cutting speed in m/min

3) To calucalate Machining time (t) (theoretical) fallowing formula is used

$$\mathbf{t} = \frac{L}{f * N}\ \textbf{in min}$$

L = Distance travelled by the tool in the direction of feed in single cut.
F = Feed in mm/rev
N = speed in rpm

VI. RESULTS AND DISCUSSION

In the first run experiment is performed using coolant APPRO SOL XL. Readings are tabulated in table5. Surface roughness is measured and MRR values are calculated using formulae.

Trial no	Surface Roughness In µm	Initial Weight gms	Final Weight gms	Machining Time (actual) in sec	Machining Time (theoretical) in sec	MRR (a) mm3/min	MRR (t) mm3/min
1	1.61	907.00	885.90	148.00	150.00	1089.69	984.38
2	1.56	907.00	883.60	74.00	75.00	2416.94	3937.50
3	2.23	907.00	867.10	50.00	50.00	6099.36	8859.38

4	1.62	907.00	876.50	76.00	75.00	3067.38	3937.50
5	0.70	907.00	866.70	37.00	37.50	8325.01	11812.50
6	0.79	907.00	893.40	24.00	25.00	4331.21	5906.25
7	0.22	907.00	873.90	50.00	50.00	5059.87	8859.38
8	0.43	907.00	889.30	25.00	25.00	5411.46	5906.25
9	1.15	907.00	878.30	17.00	16.67	12903.71	17718.75

Table 5: Experiment results when coolant is ON

Trial no	Surface Roughness In µm	Initial Weight gms	Final Weight gms	Machining Time (actual) In sec	Machining Time (theoretical) In sec	MRR (a) mm3/min	mrr(t) mm3/min
1	1.64	907.00	887.00	148.00	150.00	1032.88	984.38
2	1.59	907.00	876.50	74.00	75.00	3150.28	3937.50
3	2.26	907.00	865.80	50.00	50.00	6298.09	8859.38
4	1.62	907.00	877.10	76.00	75.00	3007.04	3937.50
5	0.74	907.00	869.20	37.00	37.50	7808.57	11812.50
6	0.83	907.00	887.10	24.00	25.00	6337.58	5906.25
7	0.25	907.00	867.40	50.00	50.00	6053.50	8859.38
8	0.47	907.00	884.60	25.00	25.00	6848.41	5906.25
9	1.18	907.00	879.10	17.00	16.67	12544.02	17718.75

Table 6: Experiment results when coolant is OFF

In the Second run experiment is performed in dry condition. Readings are tabulated in table6 Surface roughness is measured and MRR values are calculated using formulae.

REGRESSION MODELS

The regression equation for surface roughness when coolant is ON given by:

Surface Roughness (µm) = 0.42 - 0.00610 Cutting Speed ‘A’ (m/min) + 2.40 Feed ‘B’ (mm/rev) + 0.27 Depth of Cut ‘C’ (mm) + 0.0224 Tool Hardness ‘D’

The regression equation for MRR when coolant is ON given by:

MRR (a) mm3/min = 10621 + 23.31 cutting speed ’A’ (m/min) +47058 feed ‘B’ (mm/rev) + 7210 depth of cut ‘C’ (mm) – 246 tool hardness ‘D’

The regression equation for surface roughness when coolant is OFF given by:

Surface Roughness = 0.49 - 0.00608 cutting speed ‘A’ (m/min) + 2.53 feed ‘B’ (mm/rev) + 0.26 depth of cut ‘C’ (mm) + 0.0215 tool hardness ‘D’

The regression equation for MRR when coolant is OFF given by:

MRR (a) mm3/min = 5491 + 25.3 cutting speed 'A' (m/min) + 50288 feed 'B'(mm/rev) + 4951 depth of cut 'C' (mm) - 164 tool hardness 'D'

Source	DF	Seq SS	Adj SS	Adj MS	%p	Rank
Cutting speed(A)	2	2.2134	2.2134	1.1067	63.56	1
Feed(B)	2	0.3652	0.3652	0.1826	10.48	4
Depth of cut(C)	2	0.4161	0.4161	0.2080	11.94	3
Tool ardness(D)	2	0.4876	0.4876	0.2438	14.00	2
Total	8	3.4822				

Table 7: Analysis of Variance for surface roughness

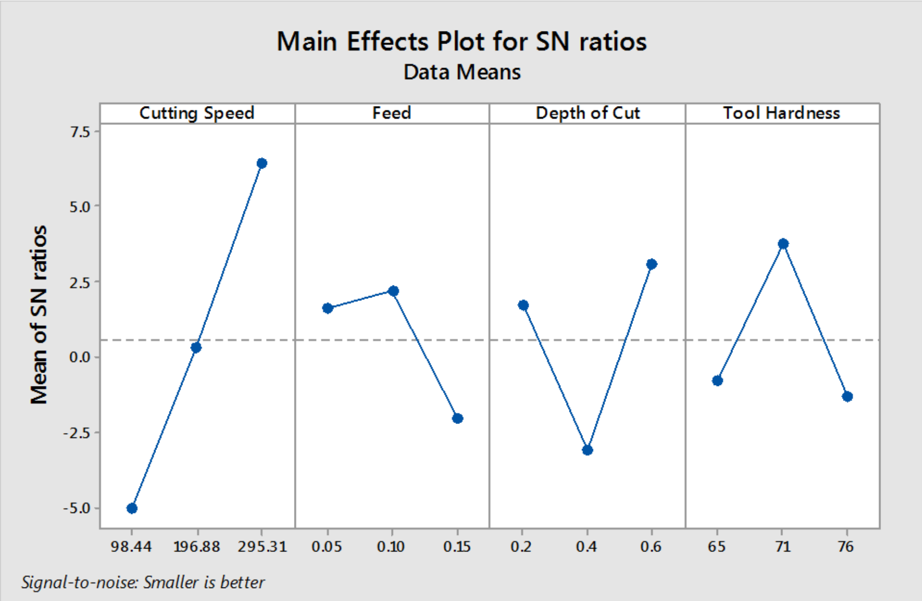

Fig.2: Effect of process parameters on surface roughness

Level	Cutting Speed (m/min) 'A'	Feed (mm/rev) 'B'	Depth of Cut (mm) 'C'	Hardness of Cutting tool (HRC) 'D'
1	-4.9884	1.6082	1.7472	-0.7508
2	0.3184	2.1887	-3.0889	3.7788
3	6.4227	-2.0442	3.0495	-1.2753
Delta	11.4111	4.2329	6.1834	5.0541
Rank	1	4	2	3

Table 8: Response table for surface roughness

Source	DF	Seq SS	Adj SS	Adj MS	%p	Rank
Cutting speed(A)	2	31728492	31728492	15864246	31.87	2
Feed (B)	2	33219867	33219867	16609933	33.37	1
Depth of cut(C)	2	14793873	14793873	7396936	14.86	4
Tool Hardness(D)	2	19783672	19783672	9891836	19.87	3
Total	8	99525902	99525902			

Table 9: Analysis of Variance for MRR

Level	Cutting Speed (m/min) 'A'	Feed (mm/rev) 'B'	Depth of Cut (mm) 'C'	Hardness of Cutting tool (HRC) 'D'
1	68.04	68.19	69.38	73.79
2	73.63	73.58	73.20	71.49
3	76.99	76.88	76.07	73.27
Delta	8.95	8.70	6.68	2.30
Rank	1	2	3	4

Table 10:Response table for MRR

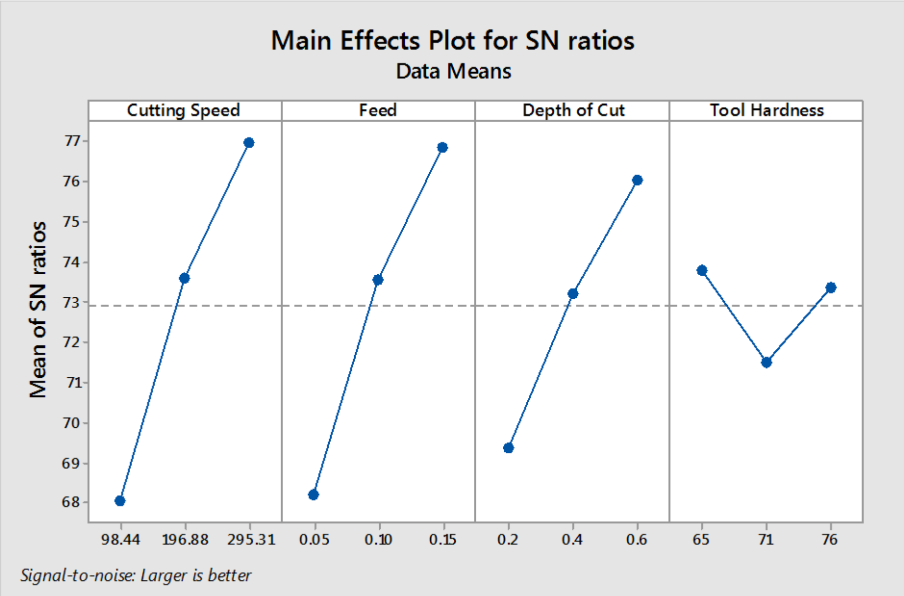

Figure3: Effect of process parameters on MRR

Source	DF	Seq SS	Adj SS	Adj MS	%p	Rank
Cutting speed(A)	2	2.20469	2.20469	1.10234	64.37	1
Feed (B)	2	0.36029	0.36029	0.18014	10.52	4
Depth of cut(C)	2	0.38869	0.38869	0.19434	11.34	3
Tool Hardness(D)	2	0.47096	0.47096	0.23548	13.75	2
Total	8	3.42462				

Table 11: Analysis of Variance for surface roughness

Level	Cutting Speed (m/min) 'A'	Feed (mm/rev) 'B'	Depth of Cut (mm) 'C'	Hardness of Cutting tool (HRC) 'D'
1	-5.13566	1.18467	1.29320	-1.03972
2	0.01450	1.71516	-3.21863	3.21057
3	5.72053	-2.30046	2.52480	-1.57148
Delta	10.85620	4.01561	5.74343	4.78204
Rank	1	4	2	3

Table 12: Response table for surface roughness

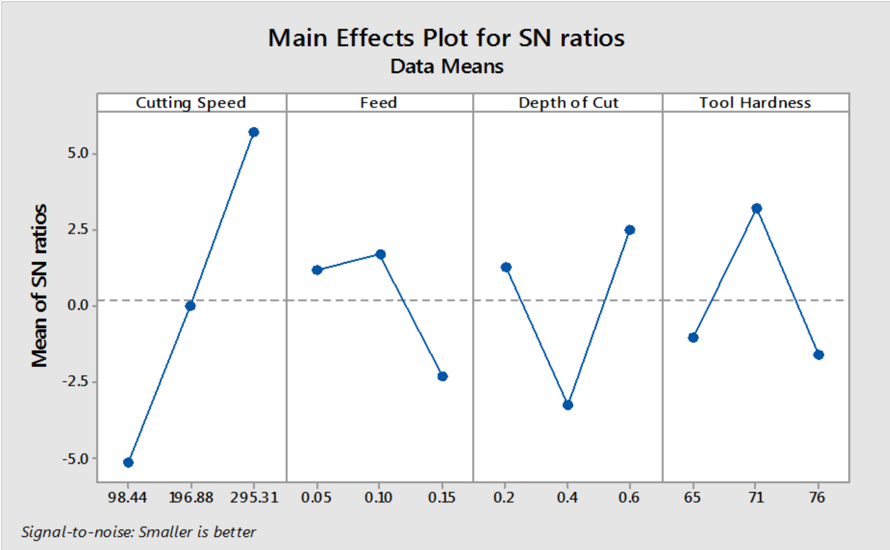

Fig.4: Effect of process parameters on surface roughness

Source	DF	Seq SS	Adj SS	Adj MS	%p	Rank
Cutting speed(A)	2	37469560	37469560	18734780	42.25	2
Feed(B)	2	37939065	37939065	18969532	42.78	1
Depth of cut(C)	2	6391089	6391089	3195545	7.20	4
Tool Hardness(D)	2	6877952	6877952	3438976	7.756	3
Total	8	88677667				

Table 13: Analysis of Variance for MRR

Level	Cutting Speed (m/min) 'A'	Feed (mm/rev) 'B'	Depth of Cut (mm) 'C'	Hardness of Cutting tool (HRC) 'D'
1	-5.13566	1.18467	1.29320	-1.03972
2	0.01450	1.71516	-3.21863	3.21057
3	5.72053	-2.30046	2.52480	-1.57148
Delta	10.85620	4.01561	5.74343	4.78204
Rank	1	4	2	3

Table 14: Response table for MRR

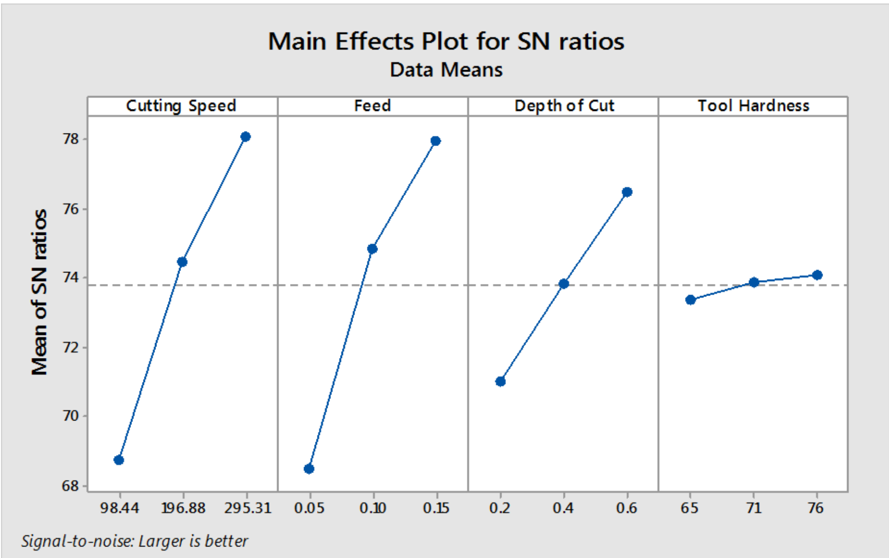

Fig 5: Effect of process parameters on MRR

Trial no	Surface roughness Ra (µm) Coolant ON	Surface roughness Ra (µm) Coolant OFF	%age improvement in Ra when coolant is used
1	1.612	1.64	1.71
2	1.56	1.59	1.89
3	2.23	2.26	1.33
4	1.62	1.62	0.00
5	0.7	0.74	5.41
6	0.79	0.83	4.82
7	0.22	0.25	12.00
8	0.43	0.47	8.51
9	1.15	1.18	2.54

Table 15: shows the effect of coolant on Surface roughness

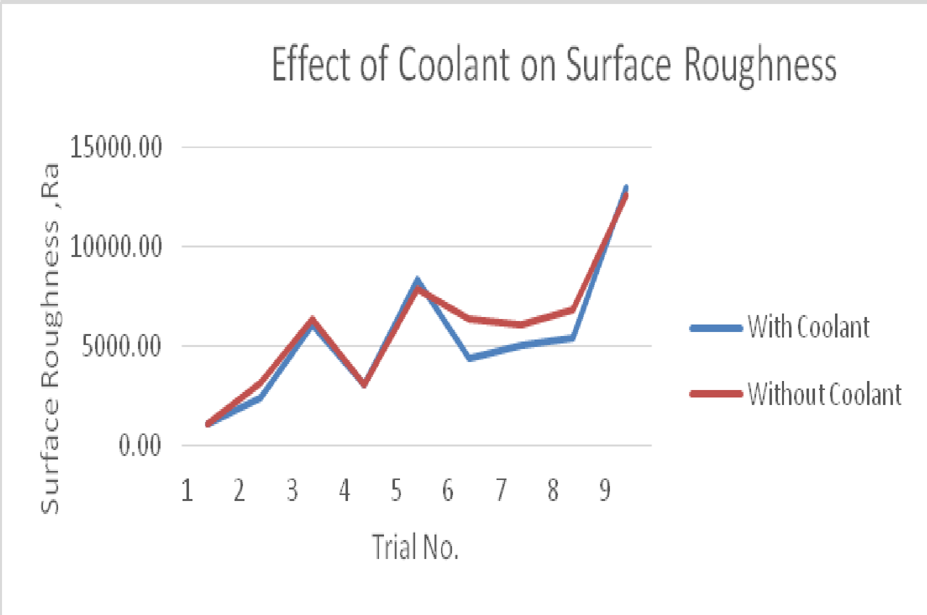

Fig 6: Effect of coolant on MRR

Trial no	MRR (a) (mm3/min) Coolant ON	MRR (a) (mm3/min) Coolant OFF
1	1089.69	1032.88
2	2416.94	3150.28
3	6099.36	6298.09
4	3067.38	3007.04
5	8325.01	7808.57
6	4331.21	6337.58
7	5059.87	6053.50
8	5411.46	6848.41
9	12903.71	12544.02

Table 16: shows the effect of coolant on MRR

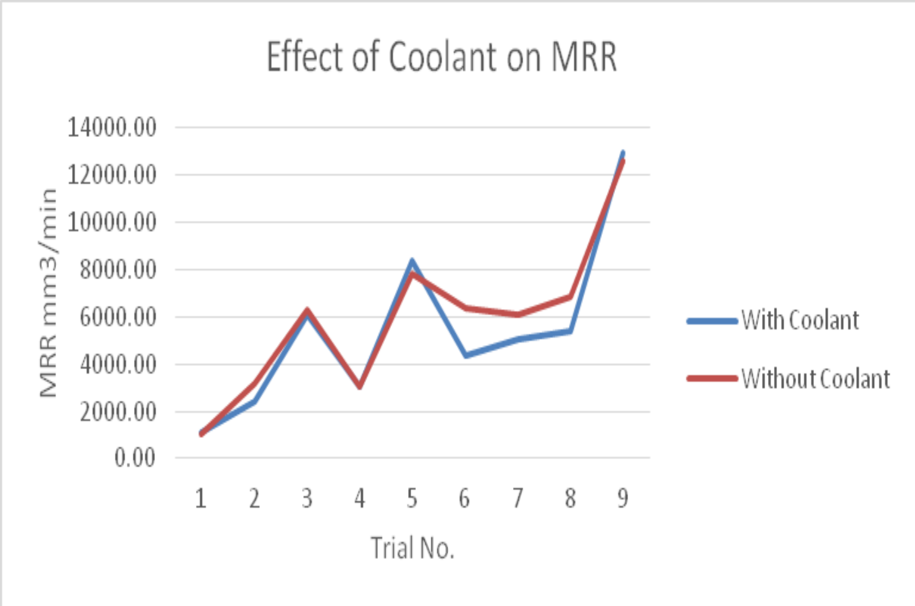

Fig 7: Effect of coolant on MRR

VII. CONCLUSION

The effect of process parameters cutting speed, Feed, Depth of cut and Tool Hardness on response Characteristics MRR and Surface roughness were studied on 20MnCr5 steel alloy in CNC Turning. Based on results obtained, the fallowing conclusions can be drawn:

- The experimental results showed that the Taguchi parameter design is an effective way of determining the optimal cutting parameters for achieving low surface roughness and maximum material removal rate.
- The relationship between cutting parameters (cutting speed, feed, depth of cut and hardness of cutting tool) and the performance measures (surface roughness and material removal rate) are expressed by multiple regression equation which can be used to estimate the expressed values of the performance level for any parameters levels.
- ANOVA suggests that cutting speed is the most significant factor and feed is most insignificant factor for surface roughness and cutting speed is the most significant factor and tool hardness is the most insignificant factor for MRR when the coolant is ON.
- ANOVA suggests that cutting speed is the most significant factor and feed is most insignificant factor for surface roughness and cutting speed is the most significant factor and feed is the most insignificant factor for MRR when the coolant is OFF.
- ANOVA (S/N Data) results shows that cutting speed, feed, depth of cut and tool hardness affects the surface roughness by 63.56%, 10.48%, 11.94% and 14% respectively when the coolant is ON.
- ANOVA (S/N Data) results shows that cutting speed, feed, depth of cut and tool hardness affects the MRR by 31.87%, 33.37%, 14.86% and 19.87% respectively when the coolant is ON.
- ANOVA (S/N Data) results shows that cutting speed, feed, depth of cut and tool hardness affects the surface roughness by 64.37%, 10.52%, 11.34% and 13.75% respectively when the coolant is OFF.
- ANOVA (S/N Data) results shows that cutting speed, feed, depth of cut and tool hardness affects the MRR by 42.25%, 42.78%, 7.20% and 7.756% respectively when the coolant is OFF.
- The result shows that surface roughness is good when coolant is used. An average improvement of 4.24% in surface roughness was found when coolant is used.
- The result shows that MRR is almost same when coolant is ON and coolant is OFF. Therefore it can be concluded that MRR does not depend much on coolant.

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