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Research Paper

OPTIMIZATION OF TURNING PARAMETERS OF EN-9 STEEL USING DESIGN OF EXPERIMENTS CONCEPTS

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Recently EN-9 steel finding many applications like shaft, axle, gears and fasteners. Due their high hardness, strength and weight ratio. Optimum machining parameters of turning operations are greatly influenced with concern along with manufacturing environment. In this experimental work turning parameters on EN-9 steel with different cutting parameters like cutting speed, feed and depth of cut greatly influenced by response parameters like surface roughness and metal removal rate. Mainly surface roughness where investigated employing L9 orthogonal array using Taguchi's design of experiments with different cutting parameters of EN-9 of turning parameters and optimized by S/N ratio and analyzed by Analysis of variance (ANOVA's).

Keywords: EN-9, Turning parameters, Taguchi DOE, S/N ratio, ANOVA

INTRODUCTION

Turning is basic metal removal process which machining with high degree of accuracy of cylindrical workpiece. Ersan Aslam *et al.* (2007) has shown that the optimized machining parameters while machining A1S1 140 steel with ceramic tool and shown that cutting speed, feed rake and depth of cut inter actions have significant influence on surface roughness. Paulo Davim (2001) express a note on the determination of optimal cutting conditions for surface finish obtained in turning using design of experiments for carbide coated tool turning tool Matsumu *et al.* (2004) performed turning operation and study the machinability of steel and give key note to determination of optimal cutting conditions for surface finish obtained in turning using design of experiments for carbide coated. Sutter (2005) gives analyzing the chip formation and chip geometrics' during high speed machining for orthogonal cutting conditions. Obvious that achievement of proper surface finish of the manufactured parts are desirable and

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essential in some applications. Ghosh and Malik (1985) have discussed the surface finish in machining and have indicated that the resultant roughness produced by a machining operation is the combined effect of two independent quantities namely ideal roughness and natural roughness. According to them, ideal roughness is a result of the geometry of the tool and the feed. It is a geometrical phenomenon and is the minimum possible magnitude of the unevenness which results from a machining operation. However natural roughness depends upon factors other than the tool, the tool geometry and feed that is Built Up Edge (BUE) formation and vibration, which adversely affect the finish. The author has also reported the expression for maximum height of unevenness in terms of side cutting edge angle, end cutting edge angle and the feed rate for both types of tools, without and with nose radius. Further they have also reported that by choosing cutting condition properly the vibration or also called chatter may be avoided. The BUE formation depends on the cutting condition and cutting speed. It is expected that, for given cutting condition the natural roughness will vary with cutting speed. It has been seen that Lin (2008) have studied the study of high speed fine turning of austenitic stainless steel . Sze-Wei *et al.* (2007) have discussed a fine tool servo system for global position error compensation for a miniature ultra-precision lathe. Vikram and Ramamoorthy (2007) have dealt with performance of coated tools during hard turning under minimum fluid application. Further Sarma and Dixit (2007) have compared the dry and air-cooled turning of grey cast iron with mixed oxide ceramic tool. Hasan *et al.* (2007) have studied The effects of cutting tool geometry and processing parameters on the surface roughness of AISI 1030 steel. However, Isik (2007) have investigated the machinability of tool steels in turning operations. Dhar *et al.* (2007), did an experimental investigation on effect of minimum quantity lubrication in machining AISI 1040 steel and Chang *et al.* (2007) have attempted to evaluate surface roughness in laser-assisted machining of aluminum oxide ceramics with Taguchi method. It is to be noted that all the above investigators have reported their results for single tool surface finish operation only. And they have concentrated on only some parameters and nobody has attempted any comprehensive accounting of result, in order consider all the possible parameters and on various types of the materials. Lack of this type of studies in the available literature produces a lot of difficulties to a designer of process operation who wants to achieve a surface finish of desired quality by controlling the various parameters during the surface finish operation. By literature review on surface roughness on the lathe machine it observed that there are many parameters which affect the surface finish of the job such as tool geometry, work piece material, cutting condition, chips, tool material and cutting parameters. But it is seen in many experiments the main factor which affected the roughness are cutting parameters. Various studies have been done on the basis of cutting parameters. Cutting parameters are Speed, Depth of Cut, and feed rate. There are many experiments which being performed for investigating the surface roughness by using single tool on lathe machine. In the proposed work an attempt has been made to compare the effect of cutting parameters on surface roughness in duplex turning and single tool turning. An attempt has been also made to develop the regression model for the duplex turning. AISI 1018 carbon steel has been taken as work piece. The optimum values of these machining parameters can improve the process characteristics such as the Metal Removal Rate (MRR), surface roughness (Ra), and Roundness Error (RE). The use of a conductive wire as a tool in electrochemical machining saves the cost of tool profiling and makes the process more economical. There are many studies that have investigated the use of wire in electrochemical cutting (Dimla, 1999; Chou *et al.*, 2002; and Montgomery, 2013). The experimental study of Feng and Wang (2002) shows that the current consumed in machining increases along with the increase in feed rate and the decrease in side gap during cutting mild steel workpiece. Feng *et al.* (2006) found that the wire feed rate that can be attained without short circuiting increases along with the increase in the applied voltage. However, this increase in wire feed rate should not exceed a particular limit in order not to extremely raise the electrolyte temperature. One application of the ECM process is Electrochemical Turning (ECT) which is used to machine hard materials of cylindrical shapes or produce grooves to hold sealing rings in flanges. In ECT, the workpiece rotates so that the axis of rotation is perpendicular to the feed of the electrode (Haci *et al.*, 2006). Hofstede and Van Den investigated the use of different electrode geometries (box-shaped electrode and plate electrode) in electrochemical turning. Wire-tool constitutes frequently a cheap alternative to a full-form tool, allowing the cutting of intricate shapes without the need for large power supplies. Statistical Process Control (SPC) has been playing a major role in controlling a product's quality since Liang *et al.* (2000) illustrated the technique of the control chart by applying statistical concepts in the manufacturing process. The statistical control of a manufacturing process is achieved through the use of SPC which assists the operator in drawing conclusions from the data indicating process status. SPC focuses on controlling the process rather than the product. That is, "If the manufacturing process is understood and controlled, the product will come out all right. Design of Experiment (DOE) is a structured, organized method used to determine the relationship between the different input factors (Xs) and the outputs (Ys) of a process. Design of experiment involves designing a set of experiments, in which all relevant factors are varied systematically. When the results of these experiments are analyzed, they help to identify the factors that most influence the results, interactions and synergies between factors, and optimal conditions. Experimental design is a strategy to gather knowledge based on the analysis.

EN-9 STEEL

EN9 is a very popular grade of throughhardening medium carbon steel, which is readily machinable in any condition (refer to our machinability guide). EN9 is suitable for the manufacture of parts such as generalpurpose axles and shafts, gears, bolts and studs. It can be further surface-hardened typically to 50-55 HRC by induction processes, producing components with enhanced wear resistance. For such applications the use of EN9D (080A42) is advisable. It is also available in a freemachining version, EN8M

(212A42) its heat treated forms possesses good homogenous metallurgical structures, giving consistent machining properties. Heat uniformly to 830/860 °C until heated through. Quench in oil or water. Can also be induction or flame hardened, Heat uniformly and thoroughly at the selected tempering temperatures, between 550 °C to 660 °C and hold at heat for one hour per inch of total thickness.

Table 1: Chemical Composition of EN-9 Steel

C	Si	Mn	S	P
0.44	0.40	1.0	0.05	0.5

Table 2: Mechanical Properties of EN-9 Steel

Max. Stress	Yield Stress	Proof Stress	Elon-gation	Impact Strength	Hard-ness
850 N/mm^2	465 N/mm^2	450 N/mm^2	16%	28J	255 BHN

PROBLEM IDENTIFICATION

The identification of turning problem for EN-9 Steel rods which cannot be tackled using conventional technique because of following problems occurs in turning process.

- High surface roughness.
- Difficult to achieve Close tolerance.
- Machining distortion.
- Poor Chip Breaking.
- Need more cutting pressure for machining.
- Need high hardness cutting tool for machining.

The above problems are have to overcome during turning process and achieve good surface finish and close dimensional accuracy.

Experimental Set Up

Figure 1: Schaublin 125 CNC Lathe

Figure 2: Tool Holder and Insert

TAGUCHI DESIGN OF EXPERIMENTS

Taguchi method is a powerful tool in quality Optimization makes use of a special design of Orthogonal Array (OA) to examine. Number of experiments used to design the orthogonal array for 3 parameters and 3 levels of milling parameters.

$$\text{Minimum experiments} = [(L - 1) \text{ X } p] + 1$$

$$= [(3 - 1) \text{ X } 3] + 1 \approx L9$$

Table 3: Design of Experiments Chart

Test No.	Spindle Speed (rpm)	Feed Rate (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

RESULTS AND DISCUSSION

After conducting the experiments of milling operation on EN-9 steel rods (diameter 20 and 100 mm length) of surface roughness values and metal removal rate are given.

Surface Roughness

- Spindle speed is a dominating parameter of turning process.
- The optimum parameter of turning operation of EN-9 steel plates were 157 m/min of cutting speed,0.03 mm/rev of Feed and 0.3 mm Depth of cut.
- However EN-9 steel plate having good machinability characteristic and produce reasonable surface finish.
- Obtained Good surface integrity and minimum wear occur during turning operation of EN-9 steel plates.
- During turning process all parameters are interact and dependant able in turning operation.

The Table 4 represent the optimum parameter of surface roughness of EN-9 steel rods were cutting speed 157 m/Min, feed rate 0.03 mm/rev and depth of cut 0.3 mm in turning operation.

Table 4: Turning Parameters of Surface Roughness

Test No.	Cutting Speed (m/min)	Feed Rate (mm/rev)	Depth of Cut (mm)	Surface Roughness (Micrometer)
1	94	0.04	0.3	2.45
2	94	0.03	0.5	2.75
3	94	0.02	0.7	2.44
4	125	0.04	0.5	2.65
5	125	0.0.3	0.7	2.85
6	125	0.02	0.5	2.96
7	157	0.04	0.7	2.15
8	157	0.03	0.3	2.10
9	157	0.02	0.5	2.95

The table represent the cutting speed is a dominating parameter in surface roughness in EN-9 steel plates in turning process.

The Table 6 shows (from F test bigger valve) cutting speed is a influencing parameter in surface roughness of EN-9 steel rods in turning operation.

Table 5: S/N Ratio of Surface Roughness

Level	Spindle Speed	Feed Rate	Depth of Cut
1	–8.106	–7.632	–7.885
2	–8.996	–8.109	–7.883
3	–7.497	–8.857	–7.831
Delta	1.499	1.224	1.052
Rank	1	2	3

Figure 3: Main Effect for Surface Roughness

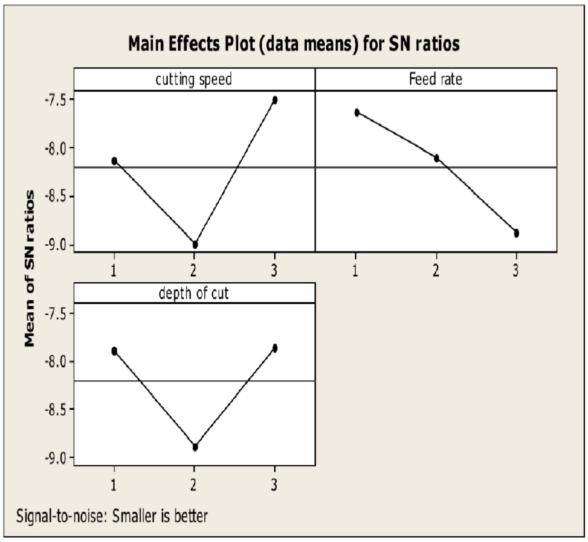


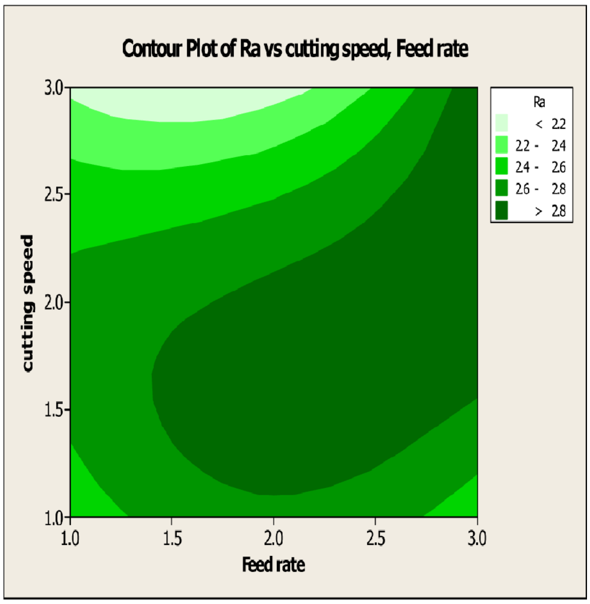
Table 6: Analysis of Variance for Surface Roughness

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cutting Speed	2	0.2762	0.2762	0.13631	1.42	0.413
Feed Rate	2	0.20389	0.20389	0.10194	1.06	0.484
Depth of Cut	2	0.17096	0.17096	0.08548	0.89	0.528
Error	2	0.19162	0.19162	0.09581		
Total	8	**0.83349**				

Metal Removal Rate

- Depth of cut is a dominating parameter of metal removal rate of turning operation.

Figure 4: Contour Plot for Surface Roughness



- The optimum parameter for Metal removal rate of turning operation were 157 m/min of cutting speed, 0.04 mm/rev of Feed and 0.7 mm of depth of cut.
- However EN-9 steel rods having good machinability characteristic and Produce reasonable surface finish.
- The large metal removal rate of EN-9 steel plate in turning operation is 4396 mm^3/sec.
- The metal removal rate is dependant parameter of turning operation.

Table 7 Turning parameters for Metal removal rate.

From Table 7 indicate the optimum parameter of metal removal rate of EN-9 steel rods were cutting speed 157 m/min feed rate 0.04 mm/rev and depth of cut 0.7 mm.

From Table 8 shows Depth of cut is a dominating parameter of Metal removal rate in En-9 steel in turning process.

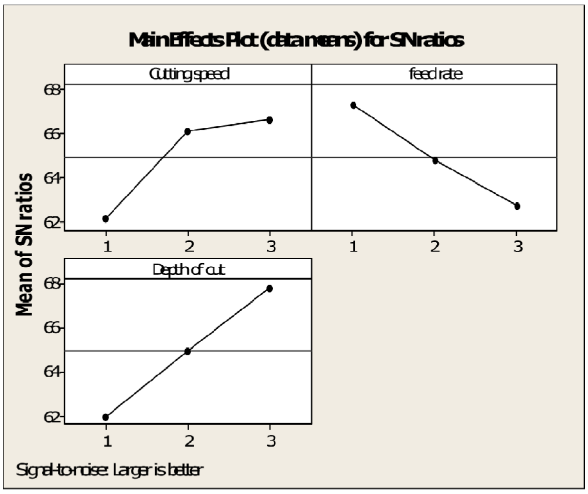
Table 7: S/N Ratio for Optimal Parameter of MRR

Test No.	Cutting Speed (m/min)	Feed Rate (mm/rev)	Depth of Cut (mm)	MRR (mm^3/min)
1	94	0.04	0.3	1,128
2	94	0.03	0.5	1,410
3	94	0.02	0.7	1,316
4	125	0.04	0.5	2,500
5	125	0.0.3	0.7	2,625
6	125	0.02	0.5	1,250
7	157	0.04	0.7	4,396
8	157	0.03	0.3	1,413
9	157	0.02	0.5	1,570

Table 8: S/N Ratio for Metal Removal Rate

Level	Spindle Speed	Feed Rate	Depth of Cut
1	62.14	67.29	62.00
2	65.09	64.79	64.95
3	66.59	62.75	67.88
Delta	4.46	4.54	5.88
Rank	3	2	1

Figure 5: Main Effect Plot for MRR



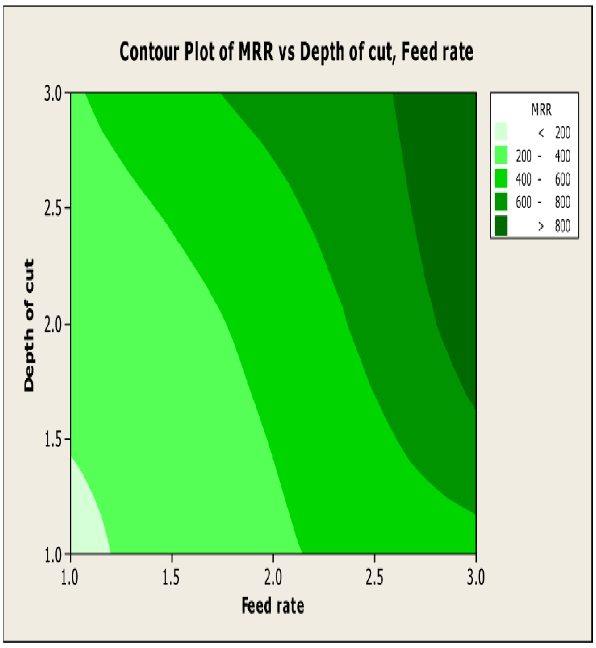
The Table 9 represent (from F test bigger value) the dominating parameter of metal removal rate of En-9 steel rods is Depth of cut in turning parameters.

Table 9: Analysis of Variance for Metal Removal Rate

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cutting Speed	2	219787	219787	1099393	3.12	0.243
Feed Rate	2	2608185	2608185	1304092	3.70	0.213
Depth Cut	2	3520143	3520143	1760071	4.99	of 0.167
Error	2	705562	705562	352781		
Total	**8**	**9032676**	**9032676**			

The Figure 6 shows the graphical representation and 3 dimensional relation between turning parameters with metal removal rate of EN-9steel plates and indicate the larger metal removal rate are 2^{nd} level of feed rate and 3^{rd} level of depth of cut.

Figure 6: Contour Plot for MMR



CONCLUSION

After conducting the experiments of turning parameters on EN-9 steel rods and optimum parameters of surface roughness and metal removal rate are given below:

- Spindle speed is a dominating parameter of turning process.
- The optimum parameter of turning operation of EN-9 steel plates were 157 m/min of cutting speed, 0.03 mm/rev of Feed and 0.3 mm Depth of cut.
- However EN-9 Steel plate having good machinability characteristic and produce reasonable surface finish.
- Feed rate is a dominating parameter of metal removal rate of turning operation.
- The optimum parameter for Metal removal rate of milling operation were 157 m/min of cutting speed, 0.04 mm/rev of Feed and 0.7 mm of depth of cut.
- The large metal removal rate of EN-9 steel plate in turning operation is 4396 mm^3/sec.
- However EN-9 steel rods having good machinability characteristic and produce reasonable surface finish.
- The metal removal rate is a independent parameter of turning operation.

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