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Determination of Optimum Process Parameters during turning on CNC Lathe of EN8 & EN24 Steels using Taguchi method and ANOVA

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***Abstract*— In all the machining operations, the quality of the surface finish is one of the most important requirements for many turned work pieces. Therefore cutting parameters must be chosen and optimized in such a way that the required surface quality can be attained. The focus of this experimental study is to optimize the cutting parameters (feed rate, spindle speed) in turning of EN8 & EN24 steel. In this, turning operation were carried out on EN8 & EN24 steel by cemented carbide coated tool insert in dry condition and the combination of the optimal levels of the parameters was obtained. In study MRR & Machining Time is also analyze by using Taguchi approach. In order to study the performance characteristics in turning operation the Signal-to-Noise ratio and Analysis of Variance (ANOVA) were employed. Taguchi method has shown that feed rate followed by Spindle speed was the combination of the optimal levels of factors while turning the specimens by cemented carbide coated tool insert of 0.8mm nose radii in dry cutting condition. The results obtained by this method will be useful to other research works for similar type of study for further research on tool vibrations, cutting forces etc.**

***Index Terms*— Material removal rate (MRR), surface roughness (SR), Analysis of variance (ANOVA), American Iron and Steel Institute (AISI), Orthogonal Array (OA)**

I. INTRODUCTION

The determination of the machinability of materials is done by the measure of surface finish. The surface roughness greatly affects the functional performance of mechanical parts such as wear resistance, fatigue strength, ability of distributing and holding a lubricant, heat generation and transmission, corrosion resistance, etc. Hence, the proper selection of cutting tools and process parameters is essential to achieve the desired quality of surface finish. Optimization seeks to maximize the performance of a system, part or component, while satisfying design constraints. The Optimization of machining parameters increases the utility for machining economics and the product quality increases to a great extent as well. Since Turning is the primary operation in most of the production process in the industry, surface finish of turned components has greater influence on the quality of the product. Surface finish in turning has been found to be influenced in varying amounts by a number of factors such as feed rate, work hardness, spindle speed, depth of cut, tool insert. The three primary process parameters in any basic Turning operation are speed, feed, and depth of cut.

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Speed always refers to the spindle and the work piece. Feed is the rate at which the tool advances along its cutting path. Depth of cut is the thickness of the material that is removed by one pass of the cutting tool over the work piece. These three variables are also effect the material removal rate and machining time which are also considerable factors in manufacturing processes.

So that, the process parameters need to be optimized to obtain the maximum surface finish & material removal rate at minimum machining time.

1.1 EN8 Material

EN8 is an unalloyed medium carbon steel with good tensile strength. It is in cold drawn or as rolled. Tensile properties can vary but are usually between 500-800 N/mm2.

Chemical composition of EN8	
Carbon	0.36-0.44%
Silicon	0.10-0.40%
Manganese	0.60-1.00%
Sulphur	0.050 Max
Phosphorus	0.050 Max

1.2. EN24 Material

EN24 is a high quality, high tensile, alloy steel and combines, high tensile strength good ductility, shock resistance and resistance to wear. It is preferred to be applied for heat treated components having large sections and subject to exacting requirements EN24 is capable of retaining good impact values at low temperatures.

Chemical composition of EN24	
Carbon	0.36-0.44%
Silicon	0.10-0.35%
Manganese	0.45-0.70%
Sulphur	0.040 Max
Phosphorus	0.035 Max
Chromium	1.00-1.40%
Molybdenum	0.20-0.35%
Nickel	1.30-1.70%

II. LITERATURE REVIEW

Hari Singh et. al. (2006) [1] Optimized setting of turning process parameters (cutting speed, feed rate and depth of cut) resulting in an optimal value of the feed force when machining EN24 steel with TiC-coated tungsten carbide inserts. EN24 is a medium-carbon low-alloy steel and finds its typical applications in the manufacturing of automobile and machine tool parts. L27orthogonal array used for the study. They found that the percent contributions of depth of cut (55·15 %) and feed rate (23·33 %) in affecting the variation of feed force are significantly larger as compared to the contribution of the cutting speed (2·63 %).

M. Nalbant et. al. (2007) [2] have studied the performance characteristics in turning processes of AISI 1030 steel bars using TiN coated tools by taking into account the signal-to-noise ratio, orthogonal array, and annova. Three variables named as nose radius, depth of cut and feed rate were taken for optimizing the surface roughness. L9 orthogonal array was used by them for the study. They found the percent of contributions of feed rate, insert radius and D.O.C. for surface roughness to be 48.54, 46.95 and 3.39, respectively.

Birhan Isik (2008) [3] Has worked on the turning operation on reinforced glass fiber plastics (GFRP) on CNC turning machine with CERMET cutting tool insert. Cutting parameters (depth of cut, cutting speed and implement geometry) and the resulting cutting forces have highly influence on the machinability surface roughness of one directional glass-fiber reinforced plastic composite. Result says that the surface roughness reduces with the increase in cutting speed. The surface roughness reduces with the increase of implement radius and cutting speed. The surface finish increases with the increase of rake angle and victual rate. An increase in cutting depth does not have a consequential reaction on the surface roughness.

Sahoo et al. (2008) [4] Reviewed for optimization of machining variables combinations emphasizing on fractal features of surface profile produced in CNC turning operation. The method used L27 Taguchi Orthogonal Array design with machining parameters: feed, spindle speed and depth of cut on three different materials viz. mild steel, alluminium and brass. It was opted that feed rate was much expressive surface finish in all three materials.

Aman Aggarwal et. al. (2008) [5] suggested that there are a number of parameters like depth of cut, feed rate, cutting speed, nose radius and cutting environment which effects in power consumption in CNC turning of AISI P-20 tool steel. They used L27 orthogonal array and face cantered central composite design conducting the experiments and utilized Design of investigation method, response surface methodology (RSM) and Taguchi's technique in analyzing the data. The cryogenic environment emerges to be the most significant factor in minimizing power consumption followed by depth of cut and cutting speed as shown by the 3D surface plots of RSM as well as by Taguchi's technique.

Anirban Bhattacharya et al. (2009) [6] have carried out the result of cutting variables on surface finish and power consumption during high speed machining of steel (AISI 1045) using Taguchi design and ANOVA. The result showed a remarkable effect of cutting speed on power consumption and surface roughness, while the other parameters have not substantially affected the response.

Bhateja et al. (2011) [7] the first aim of this paper is selection of cutting tool material & geometry & work tool material, selection of various process and performance parameters after parameter selection objectives to study various methods for the investigation for that motive literature review and industrial survey is obtained. The machining parameters and process for the performance characteristics of turning operation on CNC using different types of grades of Tungsten Carbide tool and with varying properties & surface roughness testing of work piece material to be accomplish after machining. After carrying out optimization and compare the result of cutting variables on surface roughness of dissimilar chosen geometry on EN-24 alloy steel by applying empirical method i.e. Taguchi Analysis appling Statistical Software.

Marinkovic Velibor and Madic Milos (2011) [8] presents the Taguchi robust parameter design for optimization and modeling of surface roughness single-point turning of cold rolled alloy steel 42CrMo4/AISI 4140 using TiN-coated tungsten carbide inserts was introduced. Three cutting variables, the cutting speed (80, 110, 140 m/min), the depth of cut (0.5, 1.25, 2 mm) and the feed rate (0.071, 0.196, 0.321 mm/rev), were used in the experiment. Each of the additional parameters was chosen as constant. The normal surface roughness (Ra) was taken as a measure of surface quality. The experiment was planned and accomplished by applying standard L27 Taguchi orthogonal array. The surface roughness was extremely influenced by cutting speed. The effect of feed rate was slightly smaller, whereas the effect of depth of cut was least marked. On the other hand, in qualitative terms, the influence of feed rate and depth of cut on the surface quality was dissimilar in relation to cutting speed. In fact, whereas the variation of cutting speed results better surface quality, the rise in feed rate and depth of cut led to the reduction of surface quality.

Ilhan Asilturk et. al.(2011) [9] investigated the effects of process parameters like cutting speed, depth of cut and feed on Surface roughness (Ra and Rz) in turning of AISI 4140 with coated carbide cutting tools. They used L9 orthogonal array of the Taguchi method for the optimization of surface roughness and used nine experimental runs. It's been seen that the feed rate has the most effect on Ra and Rz. A model is developed that can be used in order to determine the optimum cutting parameters for minimum surface roughness in the metal machining industries.

R S Pawade et. al. (2011) [10] has found that analysis of AE Signal during the machining could help to obtain the quality of the machined surface finish. Frequency amplitude of the AE signal is influenced by the cutting speed. The edge geometry and feed rate are found to affect the number of count generated during machining deformation.

III. EXPERIMENTATION

To determine the effects of different process variables such as spindle speed and feed rate on the surface roughness of the turned specimen (EN8 & EN24). The specimen is turned

according to L9 (OA), and after turning the surface roughness is tested on MOTUTOYO SURFTEST-4 available at R&D CENTER FOR BICYCLE & SEWING MACHINE, LUDHIANA. The work piece was turned by cemented carbide tool insert with 0.8 mm nose radii under dry cutting condition.
The values of different process parameters are as follow: (Depth of cut is constant in all sets of parameters as 1mm.

TABLE 2: DETAILS OF THE TURNING OPERATION

Factors	Level 1	Level 2	Level 3
Feed (mm/rev)	0.1	0.15	0.20
Spindle Speed (rpm)	1000	1500	1800

In this experiment, the assignment of factors was carried out using MINITAB 15 Software. Using the L9 orthogonal array have been conducted on CNC Lathe Machine for turning operations.

TABLE 2: RESULTS OF EXPERIMENTS FOR TURNING OPERATION

S. NO.	Cutting Speed	Feed	Ra (EN8)	Ra (EN24)	MRR	TIME
	(m/min)	(mm/rev)	(µm)	(µm)	cm3/ min	SEC
1	69.08	0.1	2.84	2.08	6.908	12
2	69.08	0.15	3.18	2.14	10.362	8
3	69.08	0.2	3.9	2.15	13.816	6
4	103.62	0.1	1.93	1.65	10.362	8
5	103.62	0.15	2.32	1.89	15.543	5.3
6	103.62	0.2	2.73	2	20.724	4
7	124.34	0.1	1.38	1.55	12.434	6.7
8	124.34	0.15	1.72	1.57	18.652	4.4
9	124.34	0.2	1.76	1.58	24.869	3.3

The work pieces were turned according to the experimental design and surface roughness was measured by holding the work piece in v-block and the measurements were taken by three different points on turned surface. The total length of the work piece (60 mm) was divided into 2 parts and the surface roughness measurements were taken of each 20 mm around each work piece.

TABLE 3: ANOVA FOR EN8

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**	**PC**
cutting speed	2	4.3046	4.3046	2.15231	55.08	0.001	81.2526
feed rate	2	0.8368	0.8368	0.41841	10.71	0.025	15.79524
Residual Error	4	0.1563	0.1563	0.03908			2.950281
Total	8	5.2978					100

TABLE 4: ANOVA FOR EN8

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**	**PC**
cutting speed	2	10.4688	10.4688	5.2344	28.49	0.004	87.19277
feed rate	2	0.8028	0.8028	0.4014	2.18	0.228	6.686378
Residual Error	4	0.735	0.735	0.1837			6.121684
Total	8	12.0065					100

TABLE 5: ANOVA FOR MRR

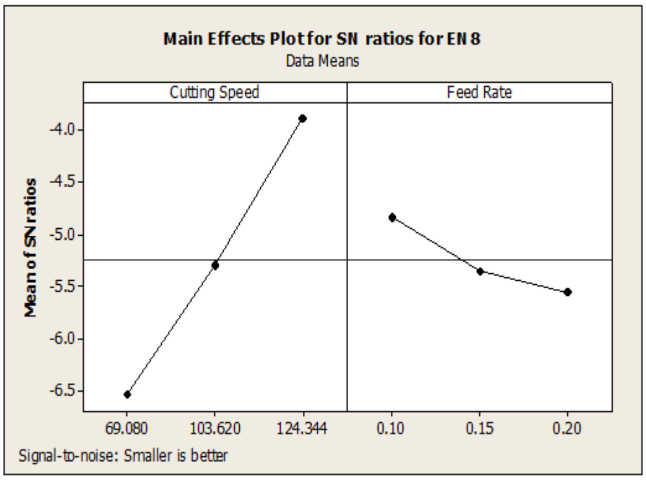
Source	DF	Seq SS	Adj SS	Adj MS	F	P	**PC**
Cutting Speed	2	30.5608	30.5608	15.2804	1314.02	0	42.54092
Feed Rate	2	41.2313	41.2313	20.6157	1772.82	0	57.39435
Residual Error	4	0.0465	0.0465	0.0116			0.064728
Total	8	71.8386					100

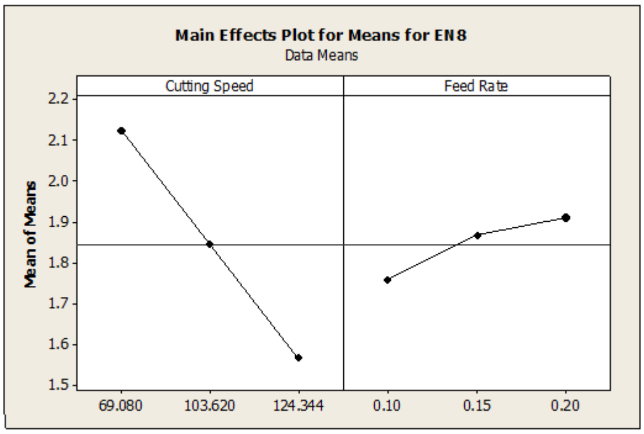
TABLE 6: ANOVA FOR MACHINING TIME

Source	DF	Seq SS	Adj SS	Adj MS	F	P	**PC**
Cutting Speed	2	23.297	23.297	11.6485	434.23	0	42.90273
Feed Rate	2	30.8976	30.8976	15.4488	575.89	0	56.89967
Residual Error	4	0.1073	0.1073	0.0268			0.197599
Total	8	54.3019					100

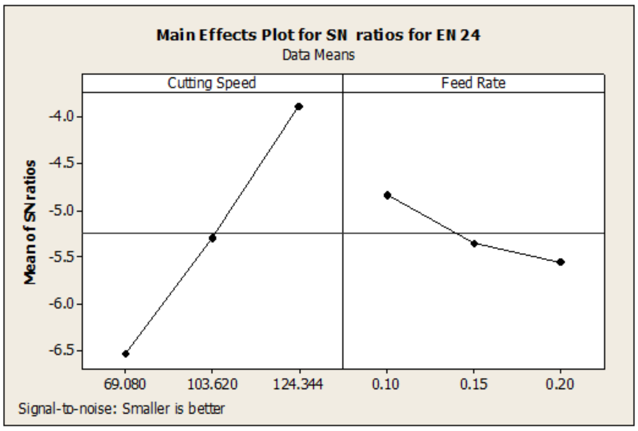
The present study used ANOVA to determine the optimum combination of process parameters more accurately by investigating the relative importance of process parameters (Ross, 1996). Table 5.1 & 5.2 presents the results of ANOVA for surface roughness (Ra). It is observed from the ANOVA table, the cutting speed (81.25 %) for EN8 & (87.19%) for EN24 is the most significant parameter followed by feed (15.79%) for EN8 & (6.68%) for EN24 in controlling the surface roughness. Statistically, F-test decides whether the parameters are significantly different. A larger F value shows the greater impact on the machining performance characteristics (Ross, 1996). Larger F-values are observed for feed as 10.71 for EN8 & 2.18 for EN24 and cutting speed as 55.08 for EN8 & 28.49 for EN24 As seen from the ANOVA table 5, the influence of the feed rate (57.39%) in affecting material removal rate (MRR) is significantly large. However, the cutting speed has optimum effect of (42.54%) in producing MRR. The influence of the feed rate (56.89%) in affecting machining time is significantly same as (MRR). However, the cutting speed has also effect of (42.90%) on machining time. It is also observed that there is also error contribution (2.9502% for surface roughness, 0.0647% for MRR & 0.1975% for machining time). It indicates the absence of the interaction effects of process parameters. In other words, interaction effects are not much negligible for minimizing surface roughness, machining time and maximizing MRR.

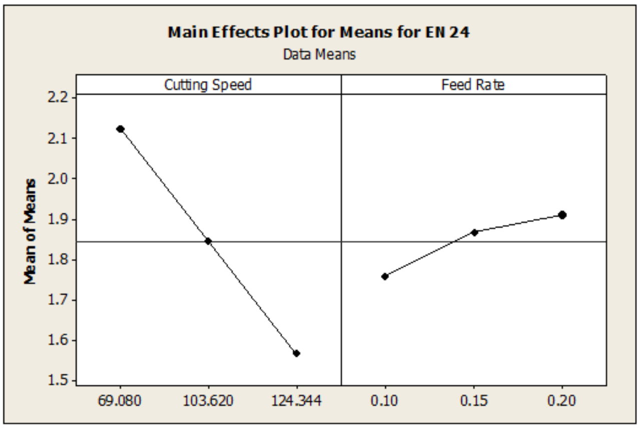
GRAPH 1: Main effect plots for Ra (EN8)



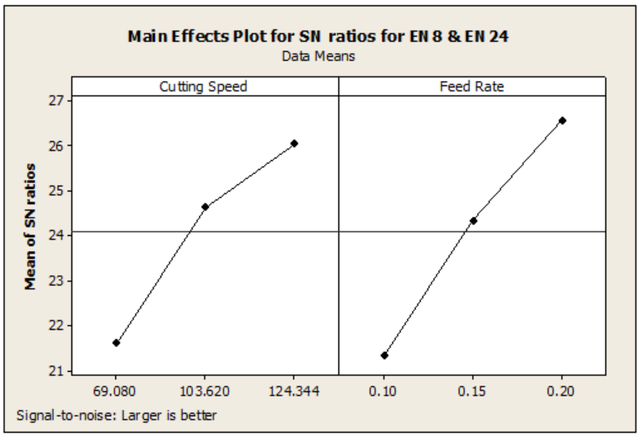


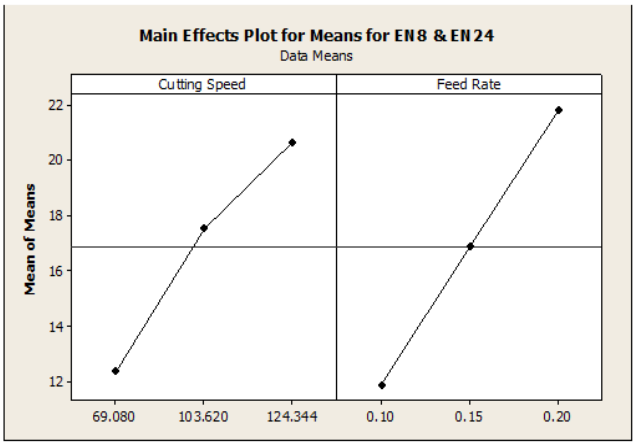
GRAPH 2: Main effect plots for Ra (EN24)



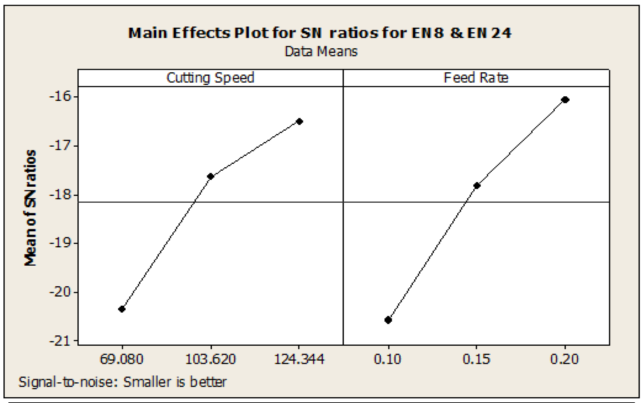


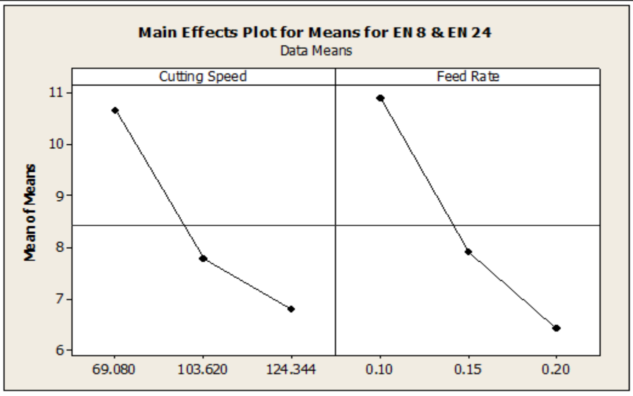
GRAPH 3: Main effect plots for MRR (EN8 & EN24)





GRAPH 4: Main effect plots for Machining time (EN8 & EN24)





The main effects plot for Ra of EN8 & EN24 **(Graph: 1&2)** shows that the surface roughness first decreases sharply with the increase in cutting speed, the surface roughness value decreases. With increase in feed rate, the surface roughness value increases. The surface roughness is "lower the better" type of quality characteristic. So the optimal factor/level combination is third level of cutting speed and first level of feed rate. So it is prescribed that cutting speed (124.344 m/min.) and feed rate of (0.10mm/rev.) produces lower surface roughness. S/N ratios plot is "larger the better" type of quality characteristic. So the optimal factor/level combination is third level of cutting speed and first level of feed rate. So it is optimized by S/N Ratio plot that cutting speed (124.344 m/min.) and feed rate of (0.10mm/rev.) produces lower surface roughness.

Graph: 3 Shows that the MRR first increases sharply with the increase in cutting speed, the MRR value increases. With increase in feed rate, the MRR value also increases. The MRR is "larger the better" type of quality characteristic. So the optimal factor/level combination is third level of cutting speed and third level of feed rate. So it is prescribed that cutting speed (124.344 m/min.) and feed rate of (0.2mm/rev.) produces higher MRR. S/N ratios plot is always "higher the better" type of quality characteristic. So the optimal factor/level combination is third level of cutting speed and third level of feed rate. So it is optimized that cutting speed (124.344 m/min.) and feed rate of (0.2mm/rev.) gives maximum material removal rate.

Graph: 4 shows that the machining time first decreases sharply with the increase in cutting speed, the machining time value decreases. With increase in feed rate, the machining time rate value also decreases. The machining time is "lower the better" type of quality characteristic. So the optimal factor/level combination is third level of cutting speed and third level of feed rate. So it is prescribed that cutting speed (124.344 m/min.) and feed rate of (0.2mm/rev.) takes lower machining time. S/N ratios plot is always "higher the better" type of quality characteristic. So the optimal factor/level combination is third level of cutting speed and third level of feed rate. So it is prescribed that cutting speed (124.344 m/min.) and feed rate of (0.2mm/rev.) takes lower machining time.

IV. CONCLUSION

1. The percentage contribution of input parameters on Surface Roughness (Ra) for EN8 is: Cutting speed = 81.25%, Feed rate = 15.79% and RE = 2.950%, signifying the cutting speed to be the most contributing factor influencing Surface Roughness.
2. The percentage contribution of input parameters on Surface Roughness (Ra) for EN8 is: Cutting speed = 87.19%, Feed rate = 6.68% and RE = 6.121%, signifying the cutting speed to be the most contributing factor influencing Surface Roughness.
3. The percentage contribution of input parameters on Material Removal Rate (MRR) is: Speed = 42.54%, Feed rate = 57.39% and RE = 0.064%, signifying the feed rate to be the most contributing factor influencing MRR.
4. The percentage contribution of input parameters on Machining Time is: Speed = 42.90%, Feed rate = 56.89% and RE = 0.197%, signifying the feed rate to be the most contributing factor influencing Machining Time.
5. The optimized machining conditions for minimizing Surface Roughness from Taguchi analysis are approaching: cutting speed 125 m/min., feed 0.1 mm/rev.
6. The optimized machining conditions for maximizing Material Removal rate from Taguchi analysis are approaching: cutting speed 125 m/min., feed 0.2 mm/rev.
7. The optimized machining conditions for minimizing Machining Time from Taguchi analysis are approaching: cutting speed 125 m/min., feed 0.2 mm/rev.

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