Optimizing of cutting parameters of EN-46 by using Taguchi Technique in CNC Turning

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Abstract - *The challenge of manufacturing industries now-a-days is the requirement of good quality product in terms of high surface finish, accuracy, less tool wear, high productivity, better economic conditions and less environmental effects. Recently EN-46 steel finding many applications like shaft,axle, gears and fasteners. Due to their high hardness, strength and weight ratio. Optimum machining parameters of turning operations are greatly influenced with concern along with manufacturing environment. The turning process has been carrying out on mild Steel (MS) rods with the grade of EN-46 having 30mm diameter and 100mm length. Mild steel rods have not been subjected to heat treatment. HSS Cutting tool is using for to perform Turning operation. An experiment will be performed to find out the set of optimum values of process parameters in order to reduce surface roughness (SR) and increase material removal rate (MRR) for the purpose of machining EN-46.Also, To analyze effect of Process parameters on surface roughness (SR) and material removal rate (MRR) by plotting the various graphs. The experiments are conducted by using Taguchi L9 orthogonal array method. Signal-to-Noise (S/N) ratio and Analysis of Variance (ANOVA) is used to analyses the effect of Cutting parameters on surface roughness and material removal rate.*

Key Words: CNC Turning Machine, EN-46, Process parameters, Machining characteristics- SR and MRR, HSS cutting tool, Taguchi method, ANOVA.

1. INTRODUCTION

The turning operation is a basic metal machining operation that is used widely in industries dealing with metal cutting. The selection of machining parameters for a turning operation is a very important task in order to accomplish high performance. By high performance, we mean good machinability better surface finish, lesser rate of tool wear, higher material removal rate, faster rate of production etc.

The surface finish of a product is usually measured in terms of a parameter known as surface roughness. It is considered as an index of product quality. Better surface finish can bring about improved strength properties such as resistance to corrosion, resistance to temperature, and higher fatigue life of the machined surface. In addition to strength properties, surface finish can affect the functional behavior of machined parts too, as in friction, light reflective properties, heat transmission, ability of distributing and holding a lubricant etc.

Turning is a metal cutting process used for the generation of cylindrical surfaces. Typically the work piece is rotated on a spindle and the tool is fed into it radially, axially or both ways simultaneously to give the required surface. The term turning, in the general sense, refers to the generation of any cylindrical surface with a single point tool. More specifically, it is often applied just to the generation of external cylindrical surfaces oriented primarily parallel to the work piece axis. The generation of surfaces oriented primarily perpendicular to the work piece axis are called facing. In turning, the direction of the feeding motion is predominantly axial with respect to the machine spindle. In facing a radial feed is dominant. Tapered and contoured surfaces require both modes of tool feed at the same time often referred to as profiling.

Fig-1: Turning operation

2. CNC MILLING PROCESS PARAMETERS

The process parameters which will influence the experiment of optimizing while machining of the Inconel 718 super alloy are listed below:

1) Cutting speed (rpm):

   The cutting speed is the cutting speed of cutter of milling machine, measured in revolution per minute (rev/min). The preferred speed is determined based on the material being cut. Excessive cutting speed will cause premature tool wear, breakages, and can cause tool chatter, all of which can lead to potentially dangerous conditions. Using the correct cutting speed for the material and tools will greatly affect tool life and the quality of the surface finish.

2) Feed Rate (mm/min):

It is the velocity at which the cutter is fed, that is, advanced against the work piece. It is expressed in units of distance per time for milling (typically in a millimeters per minute); with considerations of how many teeth (or flutes) the cutter has then determining what that means for each tooth.

3) Depth of cut (mm):

It refers to the amount of material being taken per pass. This is how deep the tool is under the surface of the material being cut. This will be the height of the chip produced. Typically, the depth of cut will be less than or equal to the diameter of the cutting tool.

Table-1: Mechanical Properties of EN-46

Max stress N/mm^2	Yield stress N/mm^2	Proof stress N/mm^2	Elongation %	Impact strength (Joules)	Hardness (BHP)
930	520	495	10	35J	300

Table-2: Chemical composition of EN-46

Chemical composition of EN-46				
C	Si	Mn	S	P
0.49	1.98	0.90	0.047	0.044

3. MACHINING CHARACTERISTICS

The most important machining characteristics considered in the present work are:

1) Surface Roughness (R_a): Surface finish is an essential requirement in determining the surface quality of a product. The average surface roughness is the integral absolute value of the height of the roughness profile over the evaluation length (L) and was represented by the equation given below.

Where 'L' is the length taken for the formula,

$$R_a = \frac{1}{L}\int_0^L |Y(x)dx|$$

Observation and 'Y' is the ordinate of the profile curve.Surface roughness tester (Stylus probe type profilometer) is uses to measure surface roughness of work piece in microns (μm).

2) Material removal rate (MRR): Material removal rate is the volume of material removed per unit time from the work piece surface. We can calculate material removal rate as the volume of material removed divided by the time taken to cut. The volume removed is the initial volume of the work piece minus the final volume. The cutting time is the time needed for the tool to move through the length of the work piece. This parameter strongly influences the finishing grade of the work piece.

$$MRR = [(Wb - Wa)/(t \times q)] \times 1000$$

Where,

Wb = Weight of the workpiece before machining (grams).
Wa = Weight of the workpiece after machining (grams). t = Machining time period (minutes).

q = Density of work piece material (grams/cm3).

3) Machining Time (min):- L/fN
Where, L=Length of tool travel (mm)
fN=Feed velocity (mm/min)

4)Tool Life (min):- VT^n=C
Where, V=Cutting speed (m/min)
T=Tool life (min.)

n=Taylor's exponent
C=Taylor's constant

4. EXPERIMENTS PERFORMED

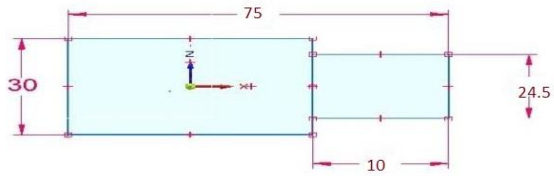

Fig 4: Dimensions of work piece after machining

1. On nine work pieces of Al 6351 the experiment is carried out.

2. All the work pieces are turned on CNC machine. The dimensions of each work piece is [Total length of work piece (L)=75 mm, Initial Diameter (D) =28 mm, Turned length of work piece (l) =10 mm & final diameter (d) =24.5mm

3. For each work piece time is measured with the help of stop watch.

4. By using the initial & final diameters and machining time, material removal rate is calculated by using the formula.

Where, D =Work piece diameter before turning in mm, d = Work piece diameter after turning in mm, L =Work piece length in mm.

5. Surface roughness of all work pieces is measured by using surface roughness tester.

6. The analysis is carried out by using Taguchi method with the help of Minitab-17 software

4. CUTTING TOOL MATERIALS

Material selection and geometry, is one of the most important factors that influence surface roughness and the mechanical properties. Tool materials, apart from having to satisfactorily endure the milling operation, affect surface roughness and tool wear. In the context of machining, a cutting tool is any tool that is used to remove material from the work piece by means of shear deformation.

In this study high speed steel (HSS) has been used as a cutting tool to perform turning process on mild steel. The tool is single point cutting tool made of high speed steel. It is grinded after each experiment and the same tool geometry is maintained. High Speed Steel is the term used to refer to tool steels that contain a mixture of more than 7% molybdenum, vanadium and tungsten along with more than 0.60% carbon. The term describes the steel's ability to cut other metals at high speeds.

Table-2: Chemical composition of HSS

Chemical Composition of HSS					
C	**Si**	**Mn**	**Fe**	**Tu**	**Cr**
0.82%	0.25%	0.30 %	Unbalanced	6.25%	4.25%

5. RESEARCH ON CNC TURNING OF EN-46

V.Paramasivam et al.[1]. They investigated the optimization of turning process parameters for EN24 steel based on Regression analysis. The L9 orthogonal is used for the experiment cutting speed, feed rate and depth of cut are considered as input parameters and material removal rate and surface roughness are output parameters. From the experiment study it can be seen that cutting speed has the significant effect on MRR and surface roughness when compared to feed rate.

Narayana reddy et al. [2].The machining parameters of 20MnCr5 steel were analyzed in CNC horizontal lathe. The Taguchi method is used for optimization. The L9 orthogonal array, signal to ratio and Analysis of variance were employed to study the performance characteristics in turning operation. In this study they have used four input parameter like cutting speed, feed rate, depth of cut and hardness of the cutting tool for identifying the output parameters like surface roughness and MRR.

Shunmugesh et al. [3] .They have made attempt to search for a set of optimal process parameter value that leads to minimize the value of machining performance. This study aimed at optimizing machining performance and the input parameters for 11sMn30. The input parameters considered for the study were speed, feed and depth of cut. The Taguchi analysis is used for optimizing the machining parameter.
Aravind kumar. [4].He has optimized the turning parameters for mild steel 1018. He used three cutting parameters to find out the maximum metal removal rate from the manufactured component. The CNC turning machine was used for this study.

For the optimization purpose the Taguchi approach with L27 orthogonal array is used. He revealed, that the feed rate in influence the material removal rate.

Anand S. Shirade et al.[5].The experiment was conducted to determine the optimum cutting parameters setting for minimizing surface roughness when turning of EN8 steel material. The L9 orthogonal array design is used for design the experiments. The analysis of variance (ANOVA) employed to analysis the influence of performance parameters during turning.

Shreemoykumarnayaket al.[6].The Investigation was carried out the effect of machining parameters during dry turning of AISI 304 austenitic stainless steel. For this study HMT heavy duty lathe machine was used. They have adopted L27 orthogonal array with three machining parameters like cutting speed, feed rate and depth of cut and three importance characteristics of machinability such as material removal rate (MRR), cutting force and surface roughness (Ra) were measured. For the optimization of machining parameters, Grey relational analysis was used.

Sachin C Borse. [7]. He was focused on optimizing turning parameters based on the Taguchi method to minimize the surface roughness and maximize the metal removal rate by using SAE 52100 steel with carbide inserts. Results of this study indicate that the feed rate is mostly influencing the surface roughness of the machined surface.

Neerajsaraswat et al.[8].They determined the optimal cutting parameters for EN9 steel in turning operation. The analysis of variance (ANOVA) and signal to noise ratio (S/N ratio) were used to study the performance characteristics in turning operation. The cutting speed, feed rate and depth of cut were selected as a input parameters to optimize the surface roughness.

6. RESEARCH GAP, PROBLEM AND CHALLENGE

Generally, Super alloys are machined on the CNC turning. EN-46 is on which optimization experiment can be performed to find out the set of optimum values of process parameters in order to reduce surface roughness (SR) and increase material removal rate (MRR). En-46 material is the most difficult material to machine. Improper selection of machining parameters causes cutting tool to wear and break quickly as well as economic losses such as damaged work piece and rejected surface quality. Machining parameters and tool geometry are the important parameters which affect the machinability properties.

6.1TAGUCHI 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.

Minimum experiments = $[(L - 1) X p] + 1$

6.1.1 DEGREES OF FREEDOM

Number of parameters = 3
Number of levels for each parameters = 3
Total degree of freedom (DOF) for 3 parameters =
3x (3-1) = 6
Minimum number of experiment = Total degree of freedom for parameters + 1
Minimum number of experiments = 6+1
Minimum number of experiments = 7
For the above process parameters and their levels, the minimum numbers of experiments to be conducted are 7. So that is why nearbyL9 orthogonal array is taken =

$[(3 - 1) X 3] + 1 = L9$

6.2TAGUCHI ORTHOGONAL ARRAY

There are three signal-to-noise ratios of common interest for optimization of static problems

1) Smaller-The-Better n = -10 Log10 [mean of sum of squares of measured data]

This is usually the chosen S/N ratio for all undesirable characteristics for which the ideal value is zero. But when the ideal value is zero, then the difference between measured data and ideal value is expected to be as small as possible. The generic form of S/N ratio becomes:- n = -10 Log10 [mean of sum of squares of {measured - ideal}]

2) Larger-The-Better n = -10 Log10 [mean of sum squares of reciprocal of measured data

By taking the reciprocals of measured data and taking the value of S/N ratio as in smaller-the-better case, we can convert it to smaller-the-better case.

Table 6.2: Taguchi Orthogonal Array

Taguchi Orthogonal Array			
Test number	Spindle speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)
1	400	0.06	0.25
2	400	0.10	0.50
3	400	0.14	0.50
4	700	0.06	0.50
5	700	0.10	0.50
6	700	0.14	0.25
7	1000	0.06	0.75
8	1000	0.10	0.25
9	1000	0.14	0.5

The mean S/N ratio for each level of the other cutting parameters has been computed in the similar manner. The mean S/N ratio for each level of the cutting parameters is summarized and called the mean S/N response table for surface roughness.

6.3.1RESPONSE TABLES FOR MRR

Table 6.3.1: Response Table for S/N Ratios Larger is better

Level	**Speed**	**Feed**	**Doc**
1	-13.535	-11.491	-9.380
2	-6.974	-8.020	-10.110
3	-6.512	-7.330	-7.350
Delta	7.023	4.160	2.760
Rank	1	2	3

6.3 .1TAGUCHI RESULT FOR MRR VS SPEED, FEED, DOC

Exp .No	SPEED (Rpm)	FEED mm/ min	DOC (mm)	MRR	SNRA
1	400	0.06	0.25	1831.36	-14.8105
2	400	0.10	0.50	3723.16	-12.0746
3	400	0.14	0.75	4232.36	-9.7194
4	700	0.06	0.50	4532.35	-9.8986
5	700	0.10	0.75	3426.52	-4.5680
6	700	0.14	0.25	4136.38	-5.9148
7	1000	0.06	0.75	5634.12	-7.7630
8	1000	0.10	0.25	4213.35	-5.4161
9	1000	0.14	0.50	4326.28	-6.3567

6.3.2 RESPONSE TABLES FOR SR

Table 6.3.2: Response Table for S/N Ratios
Smaller is better

Level	Speed	Feed	Doc
1	7.928	11.041	8.612
2	9.413	9.375	8.367
3	10.641	6.936	10.372
Delta	3.343	4.105	2.005
Rank	2	1	3

6.3.2TAGUCHI RESULT FOR Ra VS SPEED, FEED, DOC

Exp.No	SPEED (Rpm)	FEED (mm/min)	DOC (mm)	Ra (µm)	SNRA
1	400	0.06	0.25	0.363	8.8019
2	400	0.10	0.50	0.412	7.7021
3	400	0.14	0.75	0.437	7.1904
4	700	0.06	0.50	0.249	12.0760
5	700	0.10	0.75	0.328	9.6825
6	700	0.14	0.25	0.439	7.1507
7	1000	0.06	0.75	0.194	14.2440
8	1000	0.10	0.25	0.275	11.2133
9	1000	0.14	0.50	0.362	8.8258

6.4 MAIN EFFECT PLOTS ANALYSIS FOR MRR

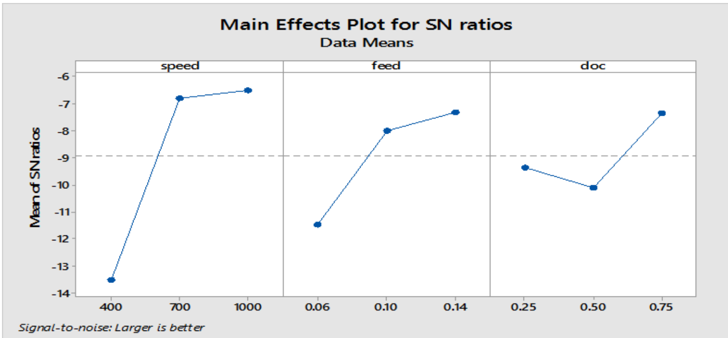

Figure 6.4: Main effect plots S/N ratios for M RR

6.5 MAIN EFFECT PLOTS ANALYSIS FOR SR

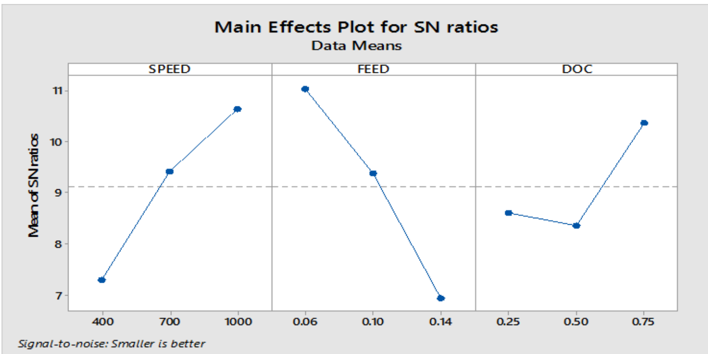

Figure 6.5.1: Main effect plots S/N ratios for SR

6.6 ANOVA RESULTS FOR S/N RATIOS OF MRR

Table 6.6.1: ANOVA for S/N ratios of MRR

Source	DF	Adj SS	Adj MS	F-Value	P-Value
SPEED	2	0.125961	0.062980	68.06	0.014
FEED	2	0.044202	0.022101	23.88	0.040
DOC	2	0.018053	0.009026	8.52	0.093
Error	2	0.001851	0.000925		
Total	8	0.190067			

It is obvious from table [6.6.1] that the speed (P=0.014) have greatest impact on material removal rate, further Feed (P=0.040) makes the second largest contribution and depth of cut (P=0.093) shows the least contribution towards material removal rate. It is obvious from table [6.6.2] that feed (P=0.531) is the most effective parameter on the surface roughness followed by speed (P=0.318) and depth of cut (0.143) being recorded as the least effective parameter.

6.6.2PERCENTAGE CONTRIBUTION OF MRR

Basic purpose of ANOVA modelling is to calculate the contribution of each Cutting parameters (Speed, Feed and Depth of Cut) through which they are affecting the Material removal Rate.

The Following contributions are given below;

a. Cutting Speed has highest significant effect on Surface Roughness which is 68.06%

b. Feed Rate has some effect on surface roughness which is 23.88%

c. Depth of cut has less significant effect on Surface Roughness which is 6.42%.

6.6.3 PERCENTAGE CONTRIBUTION OF SR

The Following contributions are given below;

a. Feed Rate has highest significant effect on Surface Roughness which is 63.64%

b. Cutting Speed has some effect on surface roughness which is 25.15%

c. Depth of cut has less significant effect on Surface Roughness which is 8.35%

6.6.4 ANOVA RESULTS FOR S/N RATIOS OF SR

Table 6.6.4: ANOVA for S/N ratios of SR

Source	DF	Adj SS	Adj MS	F-Value	P-Value
SPEED	2	0.022083	0.011041	25.15	0.318
FEED	2	0.037478	0.018739	63.64	0.531
DOC	2	0.009094	0.004547	8.35	0.143
Error	2	0.010284	0.005142		
Total	8	0.078939			

7. CONCLUSIONS

This article presents a review of research work carried out in the optimization of the process parameters for CNC turning. In this review article, surface roughness and material removal rate optimization, face milling operation and applications of EN-46 have been addressed.

Surface roughness (SR) and material removal rate (MRR) are very important factor for determining product quality. Machining parameters like cutting speed, feed rate, and depth of cut are crucial to roughness free surface. CNC Turning gives a good surface finish of EN-46. For Experimental design, Taguchi method will be used for optimization process. By using ANOVA (Analysis of variance) Method, find out the significant factor and percentage contribution of each input parameter for obtaining optimal conditions.

Using the signal to noise ratio and mean ANOVA calculations, the optimum output characteristics will be predicted by MINITAB software. This review article will covers the effect of process parameters that are influence on surface roughness (SR) and material removal rate (MRR) by plotting the various graphs. Finally from the experimentation, it is found out that the set of optimum values of process parameters in order to reduce surface roughness (SR) and increase material removal rate (MRR) for the purpose of machining EN-46.

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