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Taguchi Analysis on Surface Roughness in Turning OHNS High Carbon Steel with DNMG Carbide Insert

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Abstract

The present work focused on investigating the effect of process parameters on surface roughness and thereby optimizing parameters in turning of OHNS high carbon steel based on Taguchi technique with DNMG carbide insert. Taguchi method stresses the importance of studying the response variation using the signal-to-noise ratio, resulting in minimization of quality characteristic variation due to uncontrollable parameter. The results are analyzed using Analysis of variance (ANOVA) method. Cutting speed, feed, depth of cut were used as the process parameters whereas surface roughness selected as performance characteristic. The L9 orthogonal array based on Taguchi method was used to conduct experiments. It was observed that cutting speed is the most influential process parameters on surface roughness.
Keywords: Taguchi Method, Signal-To-Noise Ratio, Analysis of Variance, Surface Roughness

I. INTRODUCTION

Turning is a machining process in which cylindrical shapes are generated for the material parts by a single point cutting tool on lathes. The tool is fed in linear direction either in parallel or perpendicular to the axis of rotation of the work piece, or along a specified path to produce complex rotational shapes. Optimal setting of process parameters is a crucial aspect to improve the machinability of the materials. The availability of machining data from suppliers, engineering data book, experience of machine tool operators are not very scientific which further decreases productivity. Under these circumstances, optimal selection and implementation of machining parameters is necessary to enhance the productivity. The aim of the present experimental investigation is to determine the optimal levels of process parameters for optimizing the surface quality of OHNS high carbon steel work piece by employing Taguchi's orthogonal array design and Analysis of Variance (ANOVA).

A. *Taguchi Method*

Taguchi has envisaged a new method of conducting the design of experiments which are based on well-defined guidelines. This method uses a special set of arrays called orthogonal arrays. These standard arrays stipulate the way of conducting the minimal number of experiments which could give the full information of all the factors that affect the performance parameter. The crux of the orthogonal arrays method lies in choosing the level combinations of the input design variables for each experiment. Selection of optimal process parameters using various optimization techniques helps to solve the problem of improper selection of process parameters. In order to select optimal cutting parameters, manufacturing industries have depended on the use of handbook based information which leads to decrease in productivity due to sub-optimal use of machining capability. This causes high manufacturing cost and low product quality. Hence, there is a need for a systematic and methodological tool for optimization of parameters. The Taguchi's parametric design is one such effective tool for robust design.

Table - 1
Layout of an L9 orthogonal array

Experiment	*Variable 1*	*Variable 2*	*Variable 3*
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

While there are many standard orthogonal arrays available, each of the arrays is meant for a specific number of independent design variables and levels. For example, if one wants to conduct an experiment to understand the influence of three different independent variables with each variable having 3 set values (level values), and then an L9 orthogonal array might be the right choice. The L9 orthogonal array is meant for understanding the effect of 4 independent factors each having 3 factor level values. This array assumes that there is no interaction between any two factors. While in many cases, no interaction model assumption is valid, there are some cases where there is a clear evidence of interaction. A typical case of interaction would be the interaction between the material properties and temperature.

B. S/N Ratio

Usually by using classical parameter design there are a large number of experiments to be carried out when the number of the process parameter increases. To solve this task, Taguchi come out with a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. Taguchi recommends the use of the loss function to measure the performance characteristics deviating from the desired value (Glen Stuart, 1999). The value of the loss function is further transformed into a signal-to-noise ratio. There are three categories of the performance characteristics in the analysis of the S/N ratio. The S/N ratio for each level of process parameters is computed based on the *S/N* analysis (Yuin Wu, Alan Wu, 2000). Regardless of the category of the performance characteristic, the larger S/N ration corresponds to the better performance characteristics. Therefore, the optimal level of the process parameters is the level with the highest S/N ratio.

1) The smaller-the-better

The smaller-the-better characteristics is one in which the desired goal is to reduce the measured characteristics to zero. This applies, for instance to the porosity, vibration, the consumption of an automobile, tool wear, surface roughness, response time to customer complaints, noise generated from machine or engines, percent shrinkage, percent impurity in chemicals, and product deterioration.

$$[S/N = -10.\ \mathrm{Log}_{10}\ [MSD] = -10.\ \mathrm{Log}_{10} \frac{\sum \mu 2}{n} .\ y_i \quad [i=1 \text{ to } n]$$

Where MSD is the mean standard deviation, μ is the signal mean and n is the number of experiments done under experiment conditions and y_i represents the calculated characteristics.

2) The larger-the-better

The opposite of the lower-the-better is the larger-the-better characteristics. This is one in which the ideal value is infinity. This type characteristics applies to tensile strength, pull strength, car mileage per gallon of the!, reliability of a device, efficiency of engines, life of components, corrosion resistance and others.

$$[S/N = -10.\ \mathrm{Log}_{10}\ [MSD] = -10.\ \mathrm{Log}_{10} \frac{\sum 1/\mu 2}{n} y_i \quad [i=1 \text{ to } n]$$

3) The nominal-the-better

The nominal-the-better characteristics is one where a target value is specified and the goal is minimal variability around the target. This type of characteristics is generally considered when measuring dimensions such as diameter, length, thickness, width etc. Other examples include pressure, area, volume, current, voltage, resistance, and viscosity.

$$[S/N = -10.\ \mathrm{Log}_{10}\ [MSD] = -10.\ \mathrm{Log}_{10} \frac{\mu 2}{\sigma 2} .\ y_i \quad [i=1 \text{ to } n]$$

Where MSD is the mean standard deviation, μ is the signal mean and n is the number of experiments done under experiment conditions. σ is the standard deviation.

II. ANALYSIS OF VARIANCE (ANOVA)

This method was developed by Sir Ronald Fisher in the 1930s as a way to interpret the results from agricultural experiments. ANOVA is a statistically based, objective decision-making tool for detecting any differences in average performance of groups of items tested. The decision, rather than using pure judgment, takes variation into account. A statistical analysis of variance (ANOVA) is performed to see which process parameters are statistically significant. With the *S/N* and ANOVA analyses, the optimal combination of the process parameters can be predicted (Glen Stuart, 1999).

1) Average: (SN1+SN2+SN3+SN4+SN5+SN6+SN7+SN8+SN9)/9
2) Degree of Freedom: (DOF) = LEVEL-1
3) Sum of Squares: (Speed, feed, doc)
   – (Total of A1)^2/n1 + (total of A2)^2/n2 + (total of A3)^2/n3) – (total of A)^2/n
4) Mean of squares: Sum of squares/DOF
5) Sum of Squares of Error = (SSt-(SSd1+SSd2+SSd3))
   – SSt – Sum of squares of total
   – SSd1- sum of squares of speed
   – SSd2- sum of squares of feed
   – SSd3- sum of squares of depth of cuts
6) Mean squares of Error = (sum of squares of error/ DOF)
7) Percentage= (Sum of squares/ sum of squares of Total)

III. LITERATURE REVIEW

From past so many years it has been recognized that conditions during machining such as Cutting speed, Feed and Depth of Cut (DOC) should be selected to optimize the economics of machining operations. Quality of a product can be described by various quality attributes. The attributes may be quantitative or qualitative. In on-line quality control controller and related equipments are provided with the job under operation and continuously the quality is being monitored. If quality falls down the expected level the controller supplies a feedback 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 optimization problem which seeks identification of the best process condition or parametric combination for the said manufacturing process.

IV. WORK MATERIAL & CUTTING TOOL

A. OHNS (Oil hardening Non-Shrinking Die Steel / Oil hardened Nickel Steel)

OHNS is a high Carbon Steel with carbon percentage greater than 0.55%. It is an ideal type oil-hardened steel which is economical and dependable for gauging, cutting and blanking tools as well as can be relied for hardness and good cutting performance. OHNS steel refers to a variety of carbon and alloy steels that are particularly well-suited to be made into tools. Their suitability comes from their distinctive hardness, resistance to abrasion, their ability to hold a cutting edge, and/or their resistance to deformation at elevated temperatures (red-hardness). Generally used in a heat-treated state. Many high carbon tool steels are also more resistant to corrosion due to their higher ratios of elements such as vanadium and niobium.

1) Applications of OHNS

Blanking and stamping dies, Punches Rotary shear blades Thread cutting tools, Milling cutters, Reamers Measuring tools, Gauging tools, Wood working tools, Broaches i.e., all press cutting tools & punching tools for thinner materials. Small tools of Complicated design for reforming, bending & drawing. Small plastic & rubber moulds.

2) Chemical Composition and Hardness of OHNS

C – 0.95%, Si – 0.28%, Mn – 0.28%, Cr – 1.46%, P – 0.018%, S – 0.021%, Mo – 0.035%, Ni – 0.14%, V- 0.007%

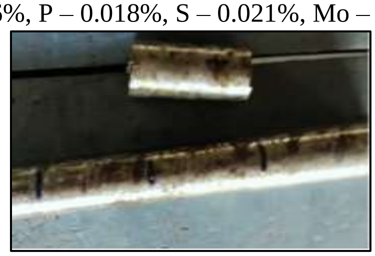

Fig. 1: OHNS bars

B. DNMG 110404 Carbide Insert Tool Bit

- D –Turning Insert Shape (Diamond)
- 11 - Turning Insert size (mm)
- N – Turning Insert Clearance angle
- 04 – Turning Insert Thickness (mm)
- M – Turning Insert Tolerance
- 04 – Turning Insert Nose Radius (mm)
- G – Insert Type

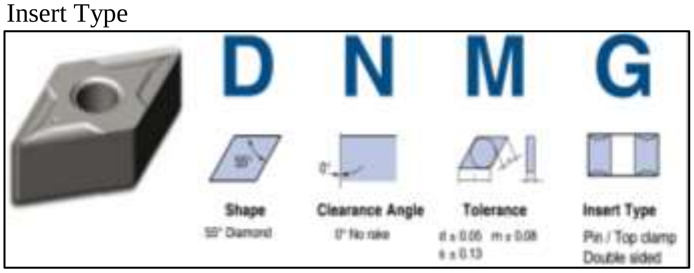

Fig. 2: Insert Nomenclature

Fig. 3: Insert with Tool holder

V. EXPERIMENTAL PROCEDURE

For OHNS material machining has been carried out with carbide insert tool bit on lathe machine. The turning parameters i.e., Speed, feed and depth of cut have been selected from orthogonal array table. Total 9 experiments have been conducted for five pieces of OHNS material with five carbide tool inserts. Surface roughness values for each experiment have been measured by Surf test instrument.

A. *Lathe Machine*

1) *Centre Lathe*

- Manufactured by - Tussor machine tool India (p) LTD Coimbatore-29' India Model-180*750
- Serial no-700002
- Manufacturing date-23/10/2007

Fig. 4: Machine setup

B. *Process Variables and Their Levels*

Based on the referred journals the following variables and levels are taken into consideration. In the present work 3 parameters cutting speed, feed and depth of cut and 3 levels are considered to conduct the experiment. The values of the 3 parameters are selected accordingly based upon the work compared to few journals. The parameters and variables along with their units are tabulated as shown in the table 2.

Table - 2
Process variables and their levels

Symbol	*Parameter*	*Levels*		
		1	*2*	*3*
A	*Speed (RPM)*	*315*	*500*	*775*
B	*Feed (mm/rev)*	*0.5*	*0.75*	*1.0*
C	*Depth of Cut (mm)*	*1.0*	*1.5*	*2.0*

Fig. 5: Machining

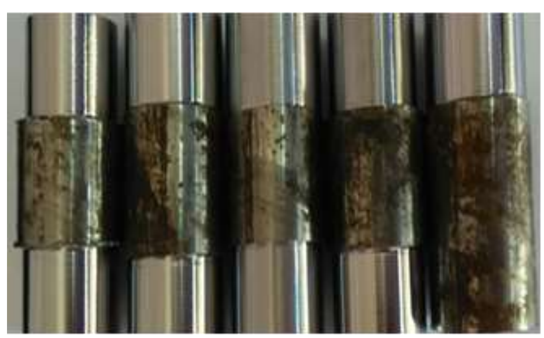

Fig. 6: OHNS Work pieces after machining.

C. *Roughness Measurement*

Roughness measurement has been done using a portable SURFTEST-type profilometer, shown in Fig. The instrument is a portable, self-contained instrument for the measurement of surface texture. The parameter evaluations are microprocessor based. The measurement results are displayed on an LCD screen and can be output to an optional printer or another computer for further evaluation. The measured profile has been digitized and processed through the dedicated advanced surface finish analysis software Talyprofile for evaluation of the roughness parameters. Surface roughness measurement with the help of SURFTEST has been shown in Figure 7. The figure shows the experimentation conducted to measure surface roughness value. The stylus is placed on the specimen in the way as shown in Fig 7 and the roughness graphs are shown below Fig 8.

Fig. 7: Surf test

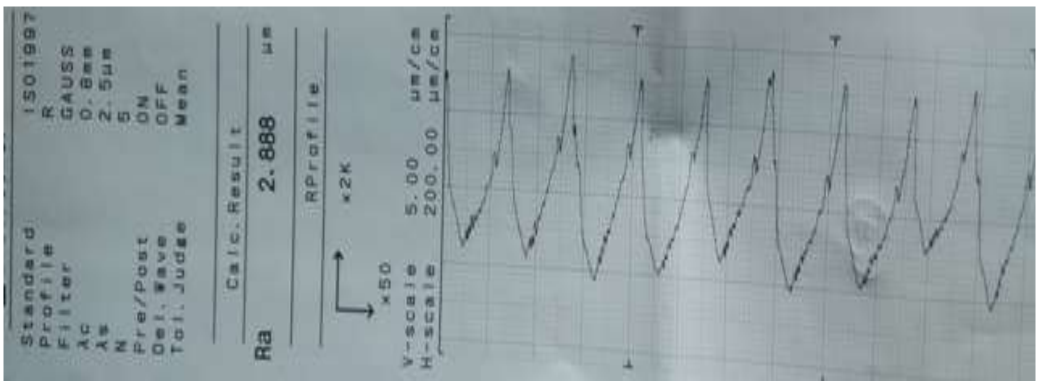

Fig. 8: Roughness graph at 500 rpm, 0.5 feed, 1.05doc. 2.888µm

VI. EXPERIMENTAL RESULTS & ANALYSIS

In the determination of the characteristics of the quality as the rates of surface roughness to be measured, MRR, cutting time, and cutting force were required to be minimum, "smaller the better" principle has been applied among the quality values expected to be reached at the end of the experiments.

Table - 3
Process variables, Roughness & S/N Ratio values

Exp. No	Variable 1	Variable 2	Variable 3	Speed	Feed	Depth Of Cut	Surface roughness values Ra (µm)			Average Ra (µm) values	S/N ratio values
1	1	1	1	315	0.5	1.0	3.0129	3.092	2.951	3.087	-15.483
2	1	2	2	315	0.75	1.5	3.328	3.096	3.250	3.224	-15.672
3	1	3	3	315	1.0	2.0	3.800	3.661	3.505	3.655	-16.228
4	2	1	2	500	0.5	1.5	2.888	2.847	2.852	2.862	-15.154
5	2	2	3	500	0.75	2.0	3.141	3.275	3.365	3.260	-15.720
6	2	3	1	500	1.0	1.0	3.304	3.118	3.104	3.175	-15.605
7	3	1	3	775	0.5	2.0	3.784	3.814	3.772	3.790	-16.575
8	3	2	1	775	0.75	1.0	3.399	3.671	3.780	3.616	-16.183
9	3	3	2	775	1.0	1.5	3.629	3.502	3.300	3.447	-15.962

A. Mean Values of Surface Finish & Response Table

The calculated S/N Values are tabulated

Table - 4
Mean values of surface finish & response table

Level/ Process Parameters	Mean Values of Surface Finish				
	A (Speed)	B (Feed)	C (Depth of Cut)	MAX-MIN	Rank
1	-15.794	-15.737	-15.757	0.747	1
2	-15.493	-15.858	-15.596	0.399	3
3	-16.240	-16.136	-16.174	0.578	2

Table - 5
Optimum levels of surface finish

Process Parameters	Optimum Levels for Surface finish
Speed	A_2
Feed	B
Depth of Cut	C_2

B. ANOVA (Analysis of Variance)

1) Calculations of ANOVA

- Average: (SN1+SN2+SN3+SN4+SN5+SN6+SN7+SN8+SN9)/9 = -15.842
- Degree Of Freedom (DOF) = LEVEL-1 =3-1 =2
- Sum of Squares :
  $(\text{Total of A1})^2/n1 + (\text{Total of A2})^2/n2 + (\text{Total of A3})^2/n3) – (\text{Total of A})^2/n$
  1) Speed: SS_d1= 0.84
  2) Feed: SS_d2 = 0.71
  3) Depth of cut: SS_d3 = 0.53
- Mean of squares: Sum of squares/DOF
  1) Speed = 0.42
  2) Feed = 0.355
  3) Depth of cut = 0.265
- Sum of Squares of Total SSt = 2.186
- Sum of Squares of Error = (SSt-(SSd1+SSd2+SSd3)) = SSe = 0.106
- Mean squares of Error = (sum of squares of error/ DOF) = MSe = 0.053
- Percentage = (Sum of squares/sum of squares of Total)
  1) Speed = 0.84/2.186 = 0.3842 = 38.42%
  2) Feed = 0.71/2.186 = 0.3247 = 32.47%
  3) Depth of cut = 0.53/2.186 =0.2424 = 24.24%
  4) Error = 0.106/2.186 = 0.0484 = 4.84%

Table - 6
Result of ANOVA

Symbol	Parameter	DOF	Sum of squares	Mean of squares	percentage
A	Speed	2	0.84	0.42	38.42%
B	Feed	2	0.71	0.355	32.47%
C	Depth of cut	2	0.53	0.265	24.24%
	error	2	0.106	0.053	4.84%

C. Confirmation Test

As the optimum levels are obtained at the same levels selected in the experiment as shown in the table 5, with roughness value 2.86μm is minimum and hence it is confirmed that the value obtained is appropriate.

VII. RESULTS AND DISCUSSION

The main objective of the experiment is to optimize the turning parameters (cutting speed, feed rate, depth of cut) to achieve low value of the surface roughness. The experimental data for the surface roughness values are shown in Table 3: for OHNS Steel. The S/N ratio values of the surface roughness are calculated, using the smaller the better characteristics are shown in Table 3: Analysis of variance for S/N ratio, Taguchi recommends analyzing data using the S/N ratio that will offer two advantages;

- It provides guidance for selection of the optimum level based on least variation around on the average value, which closest to target.
- Also it offers objective comparison of two sets of experimental data with respect to deviation of the average from the target.

The different values of the S/N ratio between maximum and minimum shown in table 4. The effect and contribution of the 3 parameters are identified and ranked according to their percentage. The response table is given as per the average of s/n ratio. The optimum levels of surface finish shown in table 5.

The cutting speed and the feed rate are two factors with the highest different in values significance 38.42% and 32.47% respectively, Table 6. Based on Taguchi prediction that the bigger different in value of S/N ratio shows a more effect on Surface roughness or more significant. Therefore, it can be concluded that, increase changes the feed rate reduces the surface roughness significantly.

VIII. CONCLUSION

The present investigation aimed at optimization of surface roughness during turning of OHNS work piece with an uncoated tool. This analysis was carried out by developing surface roughness models of Ra based on L9 orthogonal array in Taguchi optimization technique. The following are the conclusions drawn based on the tests conducted on turning of OHNS High carbon steel.

1) From the ANOVA, Table 6: and the Percentage value, the cutting speed is the only significant factor which contributes to the surface roughness i.e., 38.42 % contributed by the cutting speed on surface roughness.
2) The second factor which contributes to surface roughness is the feed rate having 32.47 %.
3) The third factor which contributes to surface roughness is the depth of cut having 24.24%.
4) The validation experiment confirms that the error occurred was 4.84%, which is less than 9.4%.
5) The optimum turning parameters are speed 500rpm, feed 0.5mm/rev and depth of cut 1.5mm for OHNS material by using DNMG carbide insert.

So, now it is found, how to use Taguchi's parameter design to obtain optimum condition with lowest cost, minimum number of experiments.

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