Optimization of turning parameters for surface roughness using taguchi method

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Abstract

The main objective of today's manufacturing industries is to produce low cost, high quality products in short time. The selection of optimal cutting parameters is a very important issue for every machining process in order to enhance the quality of machining products and reduce the machining costs. In the present work the cutting parameters (spindle speed, feed rate, and depth of cut) have been optimized in turning operations on low carbon steel and as a result of that the combination of the optimal levels of the factors was obtained to get the lowest surface roughness. The analysis also shows that the predicted values and calculated values are very close, that clearly indicates that the developed model can be used to predict the surface roughness in the turning operation of low carbon steel. The R2 (ability the Independent values to predict the dependent values) of the predictive model by using taguchi method is 94.9%.

Keyway: Surface roughness, Turning, Taguchi method, ANOVA.

1-Introduction

Increasing the productivity and the quality of the machined parts are the main challenges of metal based industry; there has been increased interest in monitoring all aspects of the machining process. Surface finish is an important parameter in manufacturing engineering. It is a characteristic that could influence the performance of mechanical parts and the production costs. The ratio between costs and quality of products in each production stage has to be monitored and immediate corrective actions have to be taken in case of deviation from desired trend. Surface roughness measurement presents an important task in many engineering applications. Many life attributes can be also determined by how well the surface finish is maintained [1].

Taguchi method is an experimental method .It is effective methodology to find out the effective performance and machining conditions. Taguchi parameter design offers a simple, systematic approach and can reduce number of experiment to optimize design for performance, quality and manufacturing cost. Signal to noise ratio and orthogonal array are two major tools used in robust design. Robust design is a methodology for obtaining product and process condition, which are minimally sensitive to the various causes of variation, and which produce high quality products with low development and manufacturing costs. Genichi Taguchi is a Japanese engineer who has been active in the improvement of japans industrial products and process since the late 1940s he has developed both the philosophy and methodology for process or product quality improvement that depends heavily on statistical concepts and tool [2]

Many surface roughness prediction systems were designed using a variety of sensors including dynamometers for force and torque. Taguchi and Analysis Of Variance (ANOVA) can conveniently optimize the cutting parameters with several experimental runs well designed. Taguchi parameter design can optimize the performance characteristics through the settings of design parameters. This study describe how to select the control factors levels (cutting speed, feed rate, Depth of cut) that can minimize the effect of noise factors on the response (surface roughness) [1]

Taguchi method consists of a plan of experiments with the objective of acquiring data in a controlled way, executing these experiments and analyzing data, in order to obtain information about the behavior of a given process. It uses orthogonal arrays to define the experimental plans and the treatment of the experimental results is based on the analysis of variance (ANOVA) [2].

1.1 Turning process

Turning is very important machining process in which a single point cutting tool removes unwanted material from the surface of a rotating cylindrical work piece. The cutting tool is fed linearly in a direction parallel to the axis of rotation. Turning is carried on a lathe that provides the power to turn the work piece at a given rotational speed and to feed to the cutting tool at specified rate and depth of cut. Therefore three cutting parameters namely cutting speed, feed and depth of cut need to be determined in a turning operation. The turning operations are accomplished using a cutting tool; the high forces and temperature during machining create a harsh environment for the cutting tool. Therefore tool life is important to evaluate cutting performance. The purpose of turning operation is to produce low surface roughness of the parts. Surface roughness is another important factor to evaluate cutting performance. Proper selection of cutting parameters and tool can produce longer tool life and lower surface roughness. Hence, design of experiments by Taguchi method on cutting parameters was adopted to study the surface roughness [6].

1.2Surface roughness

Surface properties such as roughness are critical to the function ability of machine components. Increased under standing of the surface generation mechanisms can be used to optimize machining process and to improve component functionability [10]. The surface roughness decreases with increasing cutting tool nose radius. Large nose radius tools have produced better surface finish than small nose radius tools [11]. Surface roughness is defined as irregular deviations on a scale smaller than the scale of waviness. In other words, surface roughness is described as the inherent irregularities of workpiece left by various machining processes. **Figure1** shows standard terminology and symbols for describing surface roughness. The profile (p) is the contour of any specific section through a machined surface on a plane perpendicular to the surface. Sampling length (l) is included in the measurement of average roughness height. The mean line (m) of the profile (p) is located so that the sum of areas above the mean line (within the sampling length (l)) is equal to the sum of areas below it. There are several ways to describe surface roughness. One of the most useful international parameters of surface roughness is average roughness, which is often quoted as Ra. Ra is defined as the arithmetic value of the departure of the profile from centerline along the sampling length. It is defined as:

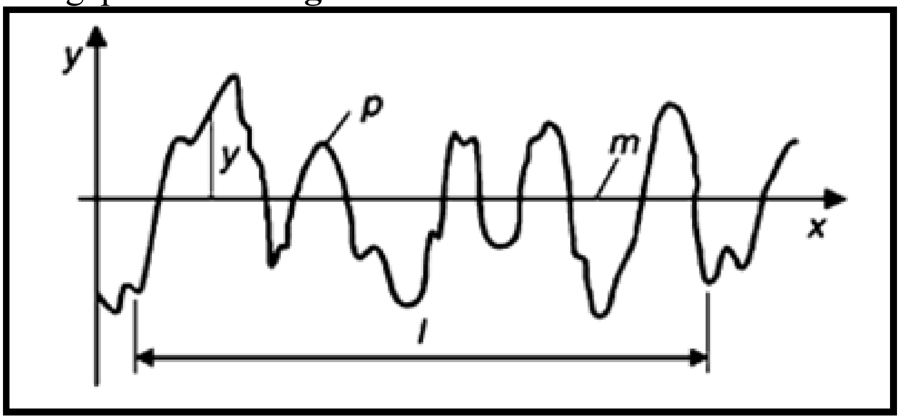

Figure (1): Surface Roughness Definition [12]

$$R_a = \frac{1}{l}\int_0^l |y(x)| dx \qquad (1)$$

Or

$$R_a = \frac{1}{n}\sum_{i=1}^{n} |y_i| \qquad (2)$$

Where Ra is average surface roughness, n number of sections, l is the sampling length and y is the ordinate of the profile curve.

2- Literature review

Traditionally, the selection of cutting conditions for metal cutting is left to the machine operator. In such cases, the experience of the operator plays a major role, but even for a skilled operator it is very difficult to attain the optimum values each time. The main machining parameters in metal turning operations are cutting speed, feed rate and depth of cut etc. The setting of these parameters determines the quality characteristics of turned parts. Suleman Neseli et al. [3] experimented to optimization of tool geometry parameters for turning operations based on the response surface methodology. In this study, experiment was design by using Taguchi L27 orthogonal array. The effect of tool geometry parameters on the surface roughness during turning of AISI 1040 steel obtained through response surface methodology (RSM) and prediction model was developed related to average surface roughness (Ra). Ilhan Asilturk and Harun Akkus [4] obtained the effect of cutting parameters on surface roughness in hard turning using the Taguchi method. In this study, dry turning test carried out on hardened AISI 4140 (51 HRC) with coated carbide cutting tools. The statistical methods of signal-to-noise (S/N) ratio and analysis of variance (ANOVA) are applied to obtained effect of cutting parameters on surface roughness. Adeel H. Suhail et al. [5] conducted experimental study to optimize the cutting parameters using two performance measures, work piece surface temperature and surface roughness. Optimal cutting parameters for each performance measure were obtained employing Taguchi techniques. The orthogonal array, signal to noise ratio and analysis of variance were employed to study the performance characteristics in turning operation.

The experimental results showed that the work piece surface temperature can be sensed and used effectively as an indicator to control the cutting performance and improves the optimization process.

3- Taguchi method

Taguchi method is a powerful tool for the design of high quality systems. It provides simple, efficient and systematic approach to optimize designs for performance, quality and cost. Taguchi method is efficient method for designing process that operates consistently and optimally over a variety of conditions. To determine the best design it requires the use of a strategically designed experiment. Taguchi approach to design of experiments in easy to adopt and apply for users with limited knowledge of statistics, hence gained wide popularity in the engineering and scientific community. The desired cutting parameters are determined based on experience or by hand book. Cutting parameters are reflected on surface roughness, surface texture and dimensional deviation turned product. In a manufacturing process it is very important to achieve a consistence tolerance and surface finish. Taguchi method is especially suitable for industrial use, but can also be used for scientific research [6].

One of the basic elements of Taguchi method is Orthogonal Array (OA). To select an appropriate orthogonal array for the experiments, the total degrees of freedom need to be computed. The degrees of freedom are defined as the number of comparisons between process parameters that need to be made to determine which level is better and specifically how much better it is [7]

The second basic element of Taguchi method is signal to noise which is the "Quality Characteristic" of performance. There are several (S/N) ratios available depending on response objective of optimization. The characteristic with higher value represents better performance (e.g. tensile strength) is called "larger is better". On the other hand, the characteristic that has lower value represents better performance (e.g machining error) is called "smaller is better" [8, 9]. The present study deals with the minimum surface roughness; therefore, "smaller is better" is used to find the optimum machining parameters that lead to this result.

4- Experimental set up and cutting conditions

4.1 Experiments

The experiments of turning low carbon steel material ,the length and diameter for workpiece was 90mm and 20mm respectively are conducted on a traditional machine named Harrison M300 as shown in **Figure 2.** The experiments required are corresponding to orthogonal array mentioned in advance, i.e. that there are nine experiments should be conducted. The carbide insert as shown in **Figure 3** is used as a cutting tool. The surface roughness was measured by using (Pocket Surf) type profilometer. .

Figure (2): Turning Machine model (Harrison M300)

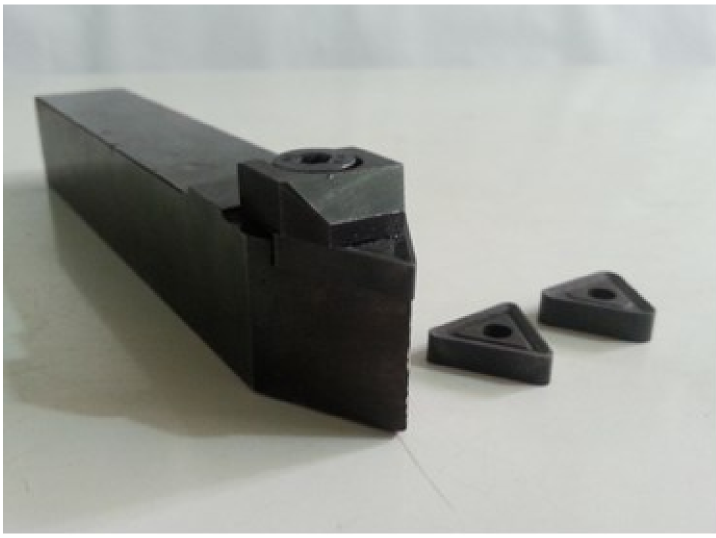

Figure (3): Holder and insert

In the present research, the standard Taguchi orthogonal array of L9 (34) has been employed**. Table 1** shows this array with cutting parameters used in this research and combination of their levels for each experiment The cutting parameters or factors that are used in this work are: spindle speed, feed rate, and depth of cut respectively. The corresponded levels to them are as shown in **Table 2**

Table (1) Taguchi orthogonal array L9.

No. of experiment	**Parameter level combination**		
	Spindle speed (rpm) A	**Feed rate (mm/rev) B**	**Depth of cut(mm) C**
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

Table (2) Factors and their levels used in experiments.

Factors	**Unit**	**Symbol**	**Conditions levels**		
			Level 1	Level 2	Level 3
Spindle speed	rpm	A	370	540	800
Feed rate	mm/rev	B	0.3	0.5	0.6
Depth of cut	mm	C	0.3	0.7	1

The cutting parameters chosen are shown in the **Table 3**. In this study, only surface roughness was studied by Taguchi method.

Table 3. Cutting conditions and response

No.of exp.	Spindle speed(rpm) A	Feed rate (mm/rev) B	Depth of cut (mm) C	Mean surface roughness (µm)	Predicted Surface roughness(µm)
1	370	0.3	0.3	0.64	0.6256
2	370	0.5	0.7	0.65	0.679
3	370	0.6	1	0.72	0.706
4	540	0.3	0.7	0.57	0.556
5	540	0.5	1	0.60	0.586
6	540	0.6	0.3	0.55	0.579
7	800	0.3	1	0.42	0.449
8	800	0.5	0.3	0.46	0.446
9	800	0.6	0.7	0.51	0.496

The research has shown two purposes. The first was to demonstrate the use of Taguchi parameter design in order to identify the optimum surface roughness with particular combination of cutting parameters. The second was to demonstrate a systematic procedure using Taguchi method in process design of turning operations. In this experiment both were achieved.
The obtained results are analyzed using Design –Expert software and all the values are shown in the Table 4. From the ANOVA **Table 4**, shows the effectiveness of each parameter toward influencing the related response characteristics within the specified range. it is concluded that the depth of cut 0.698 is the most significant parameter for minimum Ra. Feed rate 0.50 is next significant parameter for minimum Ra. The R2 (ability the Independent values to predict the dependent values) of the predictive model is 94.9%. **Figure 4**. shows the graph of effects Plot of Factors (Surface Roughness), and the optimum parameters for minimum surface roughness can be obtained from (A3B1C1), this mean when using third level for spindle speed (800) rpm , first level for feed rate (0.3) mm/rev and depth of cut (0.3) mm will give minimum surface roughness.

Table 4. Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	2	0.064156	0.064156	0.032078	17.08	0.055
B	2	0.003756	0.003756	0.001878	1.00	0.500
C	2	0.001622	0.001622	0.000811	0.43	0.698
Residual Error	2	0.003756	0.003756	0.001878		
Total	8	0.073289				

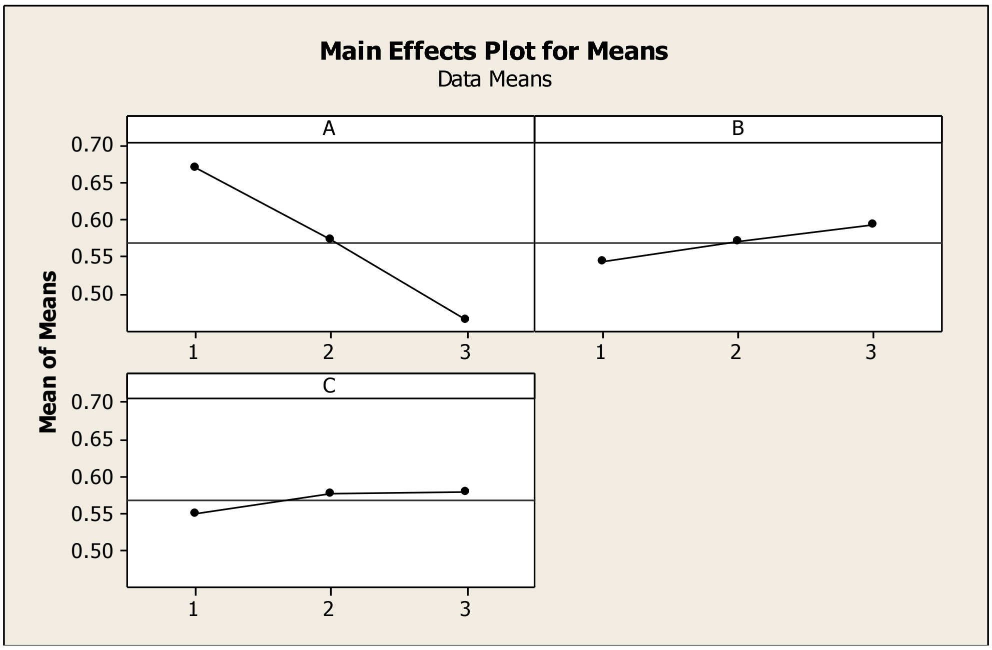

Figure (4). Main effects Plot of Factors (Surface Roughness

5- -Conclusion

The following are conclusions drawn based on the tests conducted on turning low carbon steel by the carbide insert as cutting tool.

-1 From the ANOVA table the depth of cut 0.698 is the most significant parameter for minimum Ra.

2- The second factor which significant to surface roughness is the feed rate having 0.50.

3- - The R2 (ability the Independent values to predict the dependent values) of the predictive model is 94.9%.

4- - The optimum parameters to minimum surface roughness were (A3B1C1).

5- Taguchi gives systematic simple approach and efficient method for the optimum operating conditions.

This research gives how to use Taguchi's parameter design to obtain optimum condition with lowest cost and minimum number of experiments

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تحقيــق الامثليــة مــن ظــروف الخراطــة للخشــونة الســطحية باســتخدام طريقــة تــاكوجي

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الخلاصة

ان الهدف الرئيسي اليوم من العمليات الصناعية هي الحصول على منتجات ذات كلفة قليلة ونوعية عالية بوقت قصير. ان اختيار ظروف القطع المثالية يعتبر مهم جداً لكل عمليات التشغيل وذلك لغرض تعزيز النوعية للمنتجات المشغلة وتقليل كلف التشغيل. في هذا البحث تم استخدام ظروف القطع (السرعة الدورانية, معدل التغذية وعمق القطع) في عملية الخراطة على مشغولة من فولاذ كربوني واطيء وكذلك النتائج اشتركت مع بعضها للحصول على اقل خشونة سطحية.كذلك فأن نتائج التحليل بينت القيم المتنبأة والمحسوبة كانت متقاربة , والذي يشيربوضوح الى ان النموذج المطور يمكن استخدامه للتنبؤ بالخشونة السطحية في عملية الخراطة لعينة من الفولاذ الكربوني الواطيء.وان قابلية المتغيرات المستقلة بالتنبؤ بالمتغيرات المعتمدةباستخدام طريقة تاكوجي كانت 94.9٪