Mr. Ballal Yuvaraj P., Dr. Inamdar K.H., Mr. Patil P.V. / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com
Vol. 2, Issue 3, May-Jun 2012, pp.1391-1397

"APPLICATION OF TAGUCHI METHOD FOR DESIGN OF EXPERIMENTS IN TURNING GRAY CAST IRON "

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Abstract:

In order to produce any product with desired quality by machining, proper selection of process parameters is essential. Taguchi's parameter design is an important tool for robust design, which offers a simple and systematic approach to optimize a design for performance, quality and cost. The Taguchi method of off-line quality control encompasses all stages of product /process development. However, the key element for achieving high quality at low cost is Design of Experiments (DOE). Quality achieved by means of process optimization is found by many manufacturers to be cost effective in gaining and maintaining a competitive position in the world market.

This paper describes use and steps of Taguchi design of experiments and orthogonal array to find a specific range and combinations of turning parameters like cutting speed ,feed rate and depth of cut to achieve optimal values of response variables like surface finish, tool wear, material removal rate in turning of Brake drum of FG 260 gray cast iron Material.

Keywords:

Design of experiments, orthogonal array, Process parameters, Taguchi method, Turning.

1. Introduction:

Achieving a desired level of surface quality for turned parts requires practical knowledge and skill to properly set up this type of operation with the given specifications and conditions. A manufacturing engineer or machine setup technician is often expected to utilize experience and published shop guidelines for determining the proper machining parameters to achieve a specified level of surface roughness. This must be done in a timely manner to avoid production delays, effectively to avoid defects, and the produced parts monitored for quality. Therefore, in this situation, it is prudent for the engineer or technician to use past experience to select parameters which will likely yield a surface roughness below that of the specified level, and perhaps make some parameter adjustments as time allows or quality control requires.

Engineers and technicians establishing such an operation would ideally consider other implications of setup parameters such as production schedules, processing time, and noise factors. A more methodical, or experimental, approach to setting parameters should be used to ensure that the operation meets the desired level of quality with given noise conditions and without sacrificing production time. Rather than just setting a very low feed rate to assure a low surface roughness, for example, an experimental method might determine that a faster feed rate, in combination with other parameter settings, would produce the desired surface roughness. Unfortunately, in most scenarios, time is limited and design of experiments (DOE) methods tend to be lengthy and cumbersome when considering the complex factors and noise that affect such an operation [1]. In order to optimize such an operation with such restrictions, a more efficient experimental method is needed. An excellent solution to this issue is an approach known as Taguchi Parameter Design.

2.Present theories and practices:

Kilickap et. al. [2] investigated tool wear and surface roughness in machining of homogenized SiC-p reinforced aluminium metal matrix composite. They found that tool wear was mainly affected by cutting speed, increased with increasing cutting speed. Tool wear was lower when coated cutting tool was used in comparison to uncoated one. Surface roughness influenced with cutting speed and feed rate. Higher cutting speed and lower feed rates produced better surface quality.

Luo et al. [3] carried out theoretical and experimental studies to investigate the intrinsic relationship between tool flank wear and operational conditions in metal cutting processes using carbide cutting inserts. The authors developed the model to predict tool flank wear land width which combined cutting mechanics simulation and an empirical model. The study revealed that cutting speed had more dramatic effect on tool life than feed rate.

S. Dolinšek et al. [4] tested the applicability of different cutting tools in producing tool making equipment and studied mechanisms present in high speed cutting process. They found out that cutting speed is not the main influential factor of wear, but more likely wear is the consequence of the high-speed of the tool movements (feed rate). This leads to tool wear which can no longer generate a prescribed surface quality or assure required work piece accuracy.

Hari Singh [5] did optimization of process parameters (cutting speed, feed and depth of cut), to find relation with tool life of TiC coated carbide inserts while turning En24 steel (0.4 % C). This was accomplished using Taguchi's design of experiments approach. The results were drawn and it was found that the selected process parameters significantly affect the mean and variance of the tool life of the carbide inserts. By ANOVA analysis it was found that the relative power of feed (8.78 %) in controlling variation and mean tool life is significantly smaller than that of the cutting speed (34.89 %) and depth of cut (25.80 %). The predicted optimum tool life was 20.19 min.

Gopalswamy et al. [6] applied Taguchi approach to optimize process parameters for end milling while machining hardened steel. Orthogonal array (L_{18}), signal to noise ratio and analysis of variance (ANOVA) were applied to process parameters. After analysis it was observed that adhesion and chipping were the main cause of tool wear. Multi regression equations were formulated for estimating surface finish and tool wear. Cutting speed was found to be most significant factor in surface finish and tool wear.

Kassab and Khoshnaw [7] examined the correlation between surface roughness and cutting tool vibration for turning operation. The process parameters were cutting speed, depth of cut, feed rate and tool overhanging. The experiments were carried out on lathe using dry turning (no cutting fluid) operation of medium carbon steel with different level of aforesaid process parameters. Dry turning was helpful for good correlation between surface roughness and cutting tool vibration because of clean environment. The authors developed good correlation between the cutting tool vibration and surface roughness for controlling the surface finish of the work pieces during mass production. The study concluded that the surface roughness of work piece was observed to be affected more by cutting tool acceleration; acceleration increased with overhang of cutting tool. Surface roughness was found to be increased with increase in feed rate.

3. Design of experiments and procedure:

The design of experiments and procedures are as follows:

3.1 Strategies of experimentation:

There are several strategies of experimentation, which have been used by researchers. The most widely used strategies for experimental analysis include [8]:

a. Best-guess approach: In this approach an arbitrary combination of factors are selected, then tested and its influence on output response is observed. If this initial 'best-guess' does not produce the desired results, the researchers take another 'guess' at the correct combination of factor levels. This could continue for a long time without guarantee of successes. Secondly, suppose the initial 'best-guess' produces an acceptable result, the researcher is now tempted to stop testing although there is no guarantee that the best solution has been found.

b. One-factor-at-a-time: This approach consists of selecting a starting point or baseline set of levels for each factor, then successively varying a factor over its range with the other factors being held constant at a baseline level. After all tests are performed, a series of graphs usually are constructed showing how the response variable is affected by varying each factor with all other factors held constant. The interpretation of these graphs is straightforward and easy to select the optimal combination of factor levels. However, this strategy fails to consider any possible factor interactions. One-factor-at-a-time experiments are always less efficient than other methods based on a statistical approach to design.

c. Statistically designed experiments: A correct approach to dealing with several factors is to conduct a statistically designed experiment such as a factorial experiment. In such experimental strategy, factors are varied together instead o f one at a time. Such experimental designs based on statistical approach enable the researcher to investigate the individual effects of each factor (or the main effects) and to determine whether the factors interact. To assess the effect of input parameters on output response variables, large numbers of experimental runs are required and therefore, is a time consuming task. Various design-of-experiment (DOE) methods are widely used to overcome this problem. The application of DOE requires careful planning, prudent layout of the experiment, and expert analysis of results. Therefore, considering the above aspects, the experiments were designed using Taguchi method-based design of experiments methodology as elaborated below.

4. Taguchi based Design of experiments:

Among the available methods, Taguchi design is one of the most powerful DOE methods for analyzing of experiments. It is widely recognized in many fields particularly in the development of new products and processes in quality control. The salient features of the method are as follows:

a. A simple, efficient and systematic method to optimize product/process to improve the performance or reduce the cost.
b. Help arrive at the best parameters for the optimal conditions with the least number of analytical investigations.
c. It is a scientifically disciplined mechanism for evaluating and implementing improvements in products, processes, materials, equipments and facilities.
d. Therefore, the Taguchi method has great potential in the area of low cost experimentation. Thus it becomes an attractive and widely accepted tool to engineers and scientists.

Taguchi defines three quality characteristics in terms of signal to noise (S/N) ratio which can be formulated for different categories which are as follows [6]:

a. Nominal and small are best characteristics

Data sequence for surface finish and tool wear, which are lower-the-better performance characteristics, are pre processed as per equations.

$$S/N = -10 \log (\hat{y}/s^2 y) \quad \ldots\ldots 1$$

$$S/N = -10 \log ((l/n)(\Sigma y^2)) \quad \ldots\ldots 2$$

b. Larger is best characteristics

Data sequence for material removal rate, which is higher-the-better performance characteristics, is pre processed as per equation 3.

$$S/N = -10 \log ((1/n)(\Sigma (1/y^2)) \quad \ldots\ldots 3$$

where, y is value of response variables and n is the number of observations in the experiments.

Taguchi method- based design of experiments involved following steps [9].

a. Definition of the problem
b. Identification of noise factors
c. Selection of response variables
d. Selection of control parameters and their levels
e. Identification of control factor interactions
f. Selection of the orthogonal array
g. Conducting the matrix experiments (experimental procedure and set-ups)
h. Analysis of the data and prediction of optimum level

a. Definition of the problem

A brief statement of the problem under investigation is "comparison of performance of coated carbide inserts with uncoated carbide inserts in turning gray cast iron"

b. Identification of noise factors

The environment in which experiments are performed is the main external source of variation of performance of turning process. Some examples of the environmental noise factors are temperature, vibrations and human error in operating the process.

c. Selection of response variables

In any process, the response variables need to be chosen so that they provide useful information about the performance of the process under study. Table 4.1 show various parameters used while designing the experiments. By considering all parameters given below and by taking literature review as technical base MRR, Surface finish (Ra) and tool wear are chosen as response variables.

d. Selection of control parameters and their levels:

The process parameters affecting the characteristics of turned parts are: cutting tool parameters tool geometry and tool material; work piece related parameters- metallographic, hardness, etc.; cutting parameters- cutting speed, feed, depth of cut, dry cutting and wet cutting.

Selection of cutting speed

Available literature on machining indicates that the influence of cutting speed on cutting forces and surface roughness changes with the cutting speed. Similarly, the effect of cutting speed on surface roughness has not been clearly understood so far. Most of the researchers have reported improvement in surface roughness with an increase in cutting speed. Also researchers, who have studied tool wear pattern, suggest to take increasing level of cutting speed which allows better understanding of wear patterns. Machine constraint is another reason for selection of cutting speed.

Selection of feed

It is known from the fundamentals of metal cutting that feed rate influences the chip cross-sectional area and hence the machining forces. It influences pitch of the machined surface profile and hence the machined surface roughness too [10]. An increase in feed rate increases the amount of cracks, pits on the machined surfaces due to reinforcement pull-out and fracture, which then deteriorates the surface quality/integrity and introduces higher thermal stresses on the machined surfaces. Also, effect of change in tool geometry in conjunction with feed rate on the surface quality/integrity is not adequately clear too.

Selection of depth of cut

It is known that depth of cut influences the chip load by change in chip cross-sectional area and hence the cutting forces, which in turn could influence the stability of the machining process and machined surface characteristics. The surface roughness deteriorates with an increase in depth of cut, which is attributed to the formation of unstable BUE at lower feed and higher depth of cut. However, most of the investigations have reported that surface roughness has little and/or no dependence on depth of cut. Further, it is envisaged that a change in depth of cut may vary the rate of plastic deformation. This in turn influences the mechanical and thermal stresses and changes the residual stresses on the machined surfaces.

Considering the literature review and the available machine settings following process parameters were selected for the present work:

a. Cutting speed
b. Feed
c. Tool material
d. Depth of cut

The ranges of the selected process parameters were ascertained by conducting some preliminary experiments using one variable at a time approach. The selected parameters were kept fixed during the entire experimentation.

Table4.1: Methodology used for investigation on Gray cast iron

Work piece material	Composition %	**C**	**Mn**	**Si**	**S**	**P**	**Fe**
		2.5-3.7	0.5-1.0	0.10-0.30	0.07-0.1	0.1-0.9	remainder
Response variables	In-process	Surface finish, Tool wear, Material removal rate.					
Control variables	Tool related	Tool nose radius (0.8mm)	Tool geometry (CNMA) (Approach angle= 95°; Shank diameter =50; f_1 = 35; l_1 =60; Rake angle = -6°; Angle of inclination = -11°)	Type (Carbide inserts K10 series uncoated and TiCN and TiAlN coated)			
	Process related	Feed rate (0.2,0.25 & 0.3 mm rev^{-1})	Cutting speed (350, 400 and 450 m min^{-1})	Depth of cut (2 mm)			
Design of experiments	Taguchi method	L_{27} (3^{13}) orthogonal array					
Tools and equipments	Machine	SIMPLE TURN 5075 CNC LATHE (Fanuc Series)					
	Cutting tools	CNMA 120408					
	Tool holder	PCLNR 2525 M 12					
Assessment of response variables	Tool makers microscope Surface meter: Mitutoyo portable surface roughness tester (SJ-201P)						
Method of effect analysis	MINITAB-15 software ANOVA	Qualitative analysis of machined surfaces					
Criteria for analysis	Smaller the better	Surface finish and tool wear					
	Larger is better	Material removal rate					

e. Selection of orthogonal array

In Taguchi method-based design of experiments, to select an appropriate orthogonal array for experimentation, the total degrees of freedom (DOF) needs to be computed [8, 11]. The DOF is defined as the number of comparisons between machining parameters that need to be made to determine, which level is better and specifically how much better it is. For example, a three-level machining parameter has two DOF. The DOF associated with interaction between two machining parameters are given by the product of the DOF for the two machining parameters. In the present study, interactions between the three machining parameters will be considered. Therefore, there are 18 DOF owing to three three-level independent parameters. In this study, a L_{27} orthogonal array as shown in table 4.2, has been used because it has 26 DOF, which is higher than 18 DOF of the chosen independent parameters and their interactions. It can accommodate seven three-level parameters and three interactions at most.

Table 4.2: Design of Experiments - Taguchi Array (L_{27})

St.order	Cutting speed(m/min)	Feed (mm/rev)	Tool type	Depth of cut(constant) (mm)
1	350	0.2	UC	2
2	350	0.2	TiCN	2
3	350	0.2	TiAlN	2
4	350	0.25	UC	2
5	350	0.25	TiCN	2
6	350	0.25	TiAlN	2
7	350	0.3	UC	2
8	350	0.3	TiCN	2
9	350	0.3	TiAlN	2
10	400	0.2	UC	2
11	400	0.2	TiCN	2
12	400	0.2	TiAlN	2
13	400	0.25	UC	2
14	400	0.25	TiCN	2
15	400	0.25	TiAlN	2
16	400	0.3	UC	2
17	400	0.3	TiCN	2
18	400	0.3	TiAlN	2
19	450	0.2	UC	2
20	450	0.2	TiCN	2
21	450	0.2	TiAlN	2
22	450	0.25	UC	2
23	450	0.25	TiCN	2
24	450	0.25	TiAlN	2
25	450	0.3	UC	2
26	450	0.3	TiCN	2
27	450	0.3	TiAlN	2

5. **Selection of work and tool material**:

Gray iron is one of the oldest cast ferrous products. In spite of competition from newer materials and their energetic promotion, gray iron is still used for those applications where its properties have proved it to be the most suitable material available. Gray iron castings are readily available in nearly all industrial areas and can be produced in foundries representing comparatively less investments. Chemical composition of FG260 gray cast iron is shown in following table 5.1:

Elements	Composition %
Carbon	2.5 -3.7
Silicon	0.10-0.30
Manganese	0.5-1.0
Sulphur	0.07-0.1
Phosphorous	0.1-0.9
Iron	remainder

Table5.1 Chemical composition of gray cast iron

The work piece selected for turning under this study is brake drum. The photographic view of the brake drum is shown in the fig.5.1.

Fig.5.1. Photographic view of brake drum

5.1 Selection of tool

The recently developed tool materials like coated carbides have improved the productivity levels of difficult-to-machine materials. Table 5.2 gives the wear land size of different tool material. Thus coated carbide tool was selected for turning of cast iron.

Tool material	Tool wear(mm)	Remark
Carbide	0.76	Roughing passes
Carbide	0.25-0.38	Finishing passes
HSS	1.25	Roughing passes
HSS	0.25-0.38	Finishing passes
Cemented Oxides	0.25-0.38	Roughing and finishing passes

Table 5.2: Recommended wear land size for different tool material and operations

Cemented carbide is chosen as uncoated cutting tool material. The ISO grade selected is K10. Other details are:

Designation: CNMA 120408
Make : Teagutec inserts
Nose radius : 0.8 mm

Tool Holder: PCLNR 2525 M 12 (K_r= 95°; D_{5m} =50; f_1 = 35; l_1 =60; γ = -6°; δ = -11°) tool holder.

The machine used for turning is SIMPLE TURN 5075 CNC LATHE (Fanuc Series). The photographic view of the CNC lathe is show in the Fig. 5.2.

Fig.5.2. Photographic view of CNC lathe

6. Overall Discussion :

This paper has discussed the application of Taguchi method for find a specific range and combinations of turning parameters like cutting speed , feed rate and depth of cut to achieve optimal values of response variables like surface finish, tool wear, material removal rate in turning of Brake drum of FG 260 gray cast iron Material. 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. It is a scientifically disciplined mechanism for evaluating and implementing improvements in products, processes, materials, equipments and facilities.

7. References:

[1] Yang, W. H., & Tarng, Y. S.” Design optimization of cutting parameters for turning operations based on the Taguchi method.” Journal of Materials Processing Technology, 1998, pp. 122-129.

[2] Kılıçkap E., Cakir O., Aksoy M., Inan A.,’’ Study of tool wear and surface roughness in machining of homogenised SiC-p reinforced aluminium metal matrix composite”, Journal of Materials Processing Technology, 15 May 2005, Vol 164-165, pp. 862-867

[3] X. Luo, K. Cheng, R. Holt , X. Liu, "Modeling flank wear of carbide tool insert in metal cutting", 2005, Wear 259 (2005) 1235–1240.

[4] S. Dolinšek, J. Kopač, “Mechanism and types of tool wear particularities in advanced cutting materials”, Journal of Achievements in Materials and Manufacturing Engineering, November 2006, Volume 19 Issue 1.

[5] Hari Singh, “Optimizing Tool Life of Carbide Inserts for Turned Parts using Taguchi’s Design of Experiments Approach”, Proceedings of the International MultiConference of Engineers and Computer Scientists 2008 Vol II, 19-21 March, 2008.

[6] Bala Murugan Gopalsamy, Biswanath Mondal and Sukamal Ghosh, “Taguchi method and ANOVA: An approach for process parameters optimization of hard machining while machining hardened steel”.Journal of Scientific and Industrial Research, Vol. ^8, August 2009, pp. 686-695.

[7] Kassab S. Y. and Khoshnaw Y. K., “The Effect of Cutting Tool Vibration on Surface Roughness of Work piece in Dry Turning Operation”, Engineering and Technology, 2007, Volume 25, Number 7, pp. 879-889.

[8] Uday A. Dabade, S. S. Joshi and N. Ramakrishnan, “Analysis of surface roughness and chip cross sectional area while machining with self propelled round insert milling cutter”

[9] Sagar Jagtap and Uday A. Dabade, "Analysis of process parameters during machining of difficult to cut material using EDM process", M. Tech. dissertation report, Walchand College of Engineering, Sangli, 11 July, 2010.

[10]*http://www*.me.emu.edu.tr/me364/ME364_cutting_materials.pdf, *Dated:26/8/2011 Valery Marinov, "Manufacturing Technology: Tool wear and Tool life"*.

[11] Madhav S. Phadke, "Quality engineering using Rombust design", Prentice hall, Englewood Cliff, New Jersey, ISBN 0-13-745167-9.