Engineering

## **Research Paper**



# Optimization of Turning Process Using Design of Experiment: A Review

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#### ABSTRACT

Turning is the removal of metal from the outer diameter of a rotating cylindrical work piece. Turning is used to reduce the diameter of the work piece, usually to a specified dimension, and to produce a smooth finish on the metal. Often the work piece will be turned so that adjacent sections have different diameters. Quality and productivity play significant role in today's manufacturing market. From customers' viewpoint quality is very important because the extent of quality of the procured product influences the degree of satisfaction of the consumers during usage of the procured goods. The objective of this paper is to review of application of Design of Experiment for optimization of turning Parameters to meet the customers' demands.

## Keywords : MRR, DOE, ANOVA, Taguchi

#### 1. Introduction

Every manufacturing industry aims at producing a large number of products within relatively lesser time. But it is felt that reduction in manufacturing time may cause severe quality loss. In order to embrace these two conflicting criteria it is necessary to check quality level of the item either on-line or off-line. The purpose is to check whether quality lies within desired tolerance level which can be accepted by the customers. Quality of a product can be described by various quality attributes. The attributes may be quantitative or qualitative. This invites optimization

problem which seeks identification of the best process condition or parametric combination for the said manufacturing process. If the problem is related to a single quality attribute then it is called single objective (or response) optimization. If more than one attribute comes into consideration it is very difficult to select the optimal setting which can achieve all quality requirements simultaneously. Otherwise optimizing one quality feature may lead severe quality loss to other quality characteristics which may not be accepted by the customers.

#### 2. Literature Review

Hardeep Singh et al. [1] used Taguchi methodology to optimize cutting parameters. The material was EN-8 steel of diameter 28mm and length 40 mm and experimental investigation presented was carried out on a HMT lathe with 5 kW power rating. For measuring Surface roughness SURFTEST-4 (Mitutoyo Make) used. In the experiment they used 4 levels. The results showed that the spindle speed contributed 63.90%, depth of cut contributed only 11.32% and feed rate contribution was least with 8.33% for measured surface roughness. The contribution for feed and RPM was 60.91% and 29.83%.whereas the depth of cut contributed only 7.82% for material removal rate. The effect of cutting parameters on surface roughness and MRR (Material Removal Rate) during machining of EN-8 was examined.



Fig. 1 Main effect plot for work-piece surface roughness Ra  $(\mu m)$ 

Figure 1 shows the main effect plot for work-piece surface roughness Ra for spindle speed, feed rate and depth of cut. The results show that with the increase in spindle speed there is a decrease in surface roughness. Accordingly, the following drawn conclusions can be drawn: It was concluded that interesting to note that spindle speed and depth of cut an approximate decreasing trend. The feed has the variable effect on surface roughness. It is interesting to note that spindle speed, feed rate and depth of cut for Material Removal Rate have increasing trend.

M Kaladhar et al. [2] in this work, Taguchi method is applied to determine the optimum process parameters for turning of AISI 304 austenitic stainless steel on CNC lathe. A Chemical vapour deposition (CVD) coated cemented carbide cutting insert is used which is produced by DuratomicTM technology of 0.4 and 0.8 mm nose radii. The machining tests are carried out on the material in cylindrical form, 330 mm long and 50 mm diameter by two layer CVD of grade TP 2500 Ti (C, N) + Al2O3 coated cemented carbide inserts of two different nose radii on Parishudh TC-250 CN, India, CNC lathe with a variable speed of up to 3250 rpm and a power rating of 7.5 kW. A centre hole was drilled on the face of the work piece to allow supporting at the tailstock the tests are conducted at four levels of Cutting speed, feed and depth of cut.

The experimental investigation was conducted to turn AISI 304 austenitic stainless steel using CVD coated cemented carbide Duratomic cutting insert at four levels of cutting parameters by employing Taguchi technique to determine the optimal levels of process parameters. The optimal combination of process parameters for maximum MRR is obtained at 190 m/min cutting speed, 0.20 mm/rev feed, 2.00 mm depth of cut and 0.4mm nose radius. A number of multiple linear regression models were developed for surface roughness and MRR. The developed models are reasonably accurate and can be used for prediction within limits. The Optimal range of surface roughness and MRR of the work piece is also predicted.

Neeraj Sharma et al. [3] they applied Taguchi method through a case study in straight turning of mild steel bar using HSS tool for the optimization of process parameters. Influences of turning process variables on surface Roughness mild steel have been studied in this research. Lathe used in turning of work piece is Centre Lathe, with 03Phase induction motor *a/c* and work piece AISI 1040 MS bars of diameter 25mm and length 45mm. The machining variables included cutting speed, feed rate and depth of cut. The variables affecting the Surface Roughness significantly were identified using ANOVA technique. Results show that cutting speed and depth of cut were significant variables to the SR of mild steel. Surface roughness decreases with increase in spindle speed. SR increases with increase in depth of cut.

B Fnides et al. [4] in this experimental, study is conducted to determine statistical models of cutting forces in hard turning of AISI H11 hot work tool steel (~ 50 HRC). This steel is free from tungsten on Cr–Mo–V basis, insensitive to temperature changes and having a high wear resistance. It is employed for the manufacture of highly stressed die-casting moulds and inserts with high tool life expectancy, plastic moulds subject to high stress, helicopter rotor blades and forging dies. The work piece is machined by a mixed ceramic tool (insert CC650 of chemical composition 70%AI2O3+30%TiC) under dry conditions. Based on 33 full factorial designs, a total of 27 tests were carried out. The range of each parameter is set at three different levels, namely low, medium and high.



Fig. 2 3D Surface plot of Fa vs Vc and f.

Mathematical models were deduced by software Minitab (multiple linear regression and response surface methodology) in order to express the influence degree of the main cutting variables such as cutting speed, feed rate and depth of cut on cutting force components.

Fa model is given by equation (1). Its coefficient of correlation R2 is 98.2%.

Fa=44.85 +0.09Vc+150.94 f +405.84ap 0.77Vc×ap.

These models would be helpful in selecting cutting variables for optimization of hard cutting process. The results indicate that the depth of cut is the dominant factor affecting cutting force components. The feed rate influences tangential cutting force more than radial and axial forces. The cutting speed affects radial force more than tangential and axial forces. Jitendra Verma et al. [5] they analyzed optimum cutting conditions to get lowest surface roughness in turning ASTM A242 Type-1 ALLOYS STEEL by Taguchi method. Experiment was designed using Taguchi method and 9 experiments were conducted by this process. The results are analyzed using analysis of variance (ANOVA) method.



Fig. 3 Percentage contribution by Pie Chart for surface roughness.

Taguchi method has shown that the cutting speed has significant role to play in producing lower surface roughness about 57.47% followed by feed rate about 16.27%. The Depth of Cut has lesser role on surface roughness from the tests. The results obtained by this method will be useful to other researches for similar type of study and may be eye opening for further research on tool vibrations, cutting forces. In this study ASTM A242 TYPE-1 ALLOY steel and 250mm long with 50 mm diameter was used as work material for experimentation using a lathe turning machine with three levels. The following are conclusions drawn based on the tests conducted on turning ASTM A242 Type-1 ALLOYS STEEL and 250 mm long with 50 mm diameter. The cutting speed is the only significant factor which contributes to the surface roughness i.e. 57.47 % contributed by the cutting speed on surface roughness. The second factor which contributes to surface roughness is the feed rate having 23.46 %. The third factor which contributes to surface roughness is the depth of cut having 16.27%. The Validation experiment confirms that the error occurred was less than 2.79% between equation and actual value. It is recommended from the above results that cutting of 18.30 to 15.78 m/min can be used to get lowest surface roughness. Taguchi gives systematic simple approach and efficient method for the optimum operating conditions.

M. Kaladhar et al. [6] investigated the effects of process parameters on surface finish and material removal rate (MRR) to obtain the optimal setting of these process parameters. And the Analysis Of Variance (ANOVA) is also used to analyze the influence of cutting parameters during machining.

In this work, AISI 304 austenitic stainless steel work pieces are turned on computer numerical controlled (CNC) lathe by using Physical Vapour Deposition (PVD) coated cermet insert (TiCN- TiN) of 0.4 and 0.8 mm nose radii. The results revealed that the feed and nose radius is the most significant process parameters on work piece surface roughness. However, the depth of cut and feed are the significant factors on MRR. Optimal range and optimal level of parameters are also predicted for responses.

Ashish Yadav et al. [7] ,In this work the relation between change in hardness caused on the material surface due the turning operation with respect to different machining parameters like spindle speed, feed and depth of cut have been investigated. Taguchi method has been used to plan the experiments and EN 8 metal selected as a work piece and coated carbide tool as a tool material in this work and hardness after turning has been measured on Rockwell scale.

The obtained experimental data has been analyzed using signal to noise and. The main effects have been calculated

and percentage contribution of various process parameters affecting hardness also determined.



Fig.4 Main effect for S/N ratio value of hardness

From main effects plots of EN 8 as shown in Figure 4, it is observed that there is decreased in hardness as the speed is increased but when speed is further increased hardness goes increased.

K Arun Vikram et al. [8] investigated the machining parameters affecting the roughness of surfaces produced in hard turning process for three different materials like EN8 steel, Aluminium alloy and Copper alloy under dry conditions. Three parameters were selected for study: cutting speed, feed and material hardness. For the three materials like Aluminium alloy, copper alloy and EN8 steel impact of increase in feeds versus decrease in cutting speeds with constant depth of cut adopted to analyze the influence of these parameters on the generated surface roughness. Regression analysis using MINITAB software for all the three material turning operation data mining was used to create model for the prediction of the average surface roughness (Ra) in terms of cutting speed, feed and material hardness and 67.2% of R2 and 47.52% of R2(adj) were obtained. The investigations of this study indicate that the cutting parameters like cutting speeds and feeds are the primary influencing factors, which affect the surface finish when machining with new tool inserts. The results indicate that feed is the dominant factor affecting the surface roughness, followed by cutting speed and hardness of the material.

S Thamizhmanii et al. [9] they have analyzed the surface roughness produced by turning process on hard martensitic stainless steel by Cubic Boron Nitride cutting tool. The experiments were designed using various operating parameters like cutting speed, feed rate and depth of cut. These operating parameters are predominantly used in carrying out the experiments. Low surface roughness was produced at cutting speed of 225 m/min with feed rate of 0.125 mm/rev and 0.50 mm depth of cut (doc). However, moderate cutting speed of 175 m/min under above feed rate and doc is an ideal operating parameters taking flank wear in to account. All experiment data were obtained on AISI 440 C hardened steel having hardness between 45 to 55 HRC. The surface roughness was measured using Mitutoyo SJ 400 make. The work piece material was received as 1000 mm length bar having 50 mm diameter. This was cut to 350 mm length.

The followings conclusions were drawn based on experiments conducted on hard AISI 440 C stainless steel. 1. The surface roughness was 23 micron at high cutting speed of 225 m/min with feed rate of 0.125 and 0.50 mm doc. This may be ideal cutting speed to operate. 2. However, operating at 175 cutting speed with 0.125 feed rate and doc of 1.00 mm may be more suitable taking the flank wear in to consideration.

S Thamizhmanii et al. [10] optimized the surface roughness, tool wear and cutting force by hard turning process. The Taguchi parameter design method is an efficient method in which response variable can be optimized, given various controls and using fewer experimental runs. Hard turning is the latest trend in all manufacturing industries and it is a profitable

alternative to grinding. The hard turning removes unwanted material in a single cut rather than grinding in order to reduce process time, set up time, operating cost, surface roughness and to produce components economically. The experiments were conducted in a Hass make CNC machine having spindle speed of 6000 rpm and power of the machine is 35 KW/HP. The cutting tool was CBN, manufactured by Mitsubishi having code MB8025 with three cutting edges. The tool holder used was MTJNL 2020K16N. In the process of analyses, material having hardness between 54-58 was considered and three CBN cutting tool were used to conduct 18 tests.



Fig, 5 Tests Vs Surface Roughness and flank wear.

The response of surface roughness and flank wear taken for discussion and analyses. The experimental results show that there is a good agreement between surface roughness and flank wear both by equations and experiments by Taguchi method.

M Kaladhar et al. [11] they optimization of machining parameters in turning of AISI 202 austenitic stainless steel using CVD coated cemented carbide tools. During the experiment, process parameters such as speed, feed, depth of cut and nose radius are used to explore their effect on the surface roughness (Ra) of the work piece. The experiments have been conducted using full factorial design in the Design of Experiments (DOE) on Computer Numerical Controlled (CNC) lathe In the Experimental the machining process was studied under DOE whereby the factorial portion is a full factorial design (24) with all combinations of the factors at two levels. Cutting tests were carried out on 10 hp CNC lathe machine under dry conditions. The machining process on CNC lathe is programmed by speed, feed, and depth of cut. In total 16 work pieces (Ф25 mm x 70mm) are prepared. These work pieces cleaned prior to the experiments by removing 0.5mm thickness of the top surface from each work piece in order to eliminate any surface defects and wobbling. They find 57.59% contributed by the feed on surface roughness. In order to obtain a good surface finish on AISI 202 steel, higher cutting speed, lower feed rate, lower depth of cut.

Suleiman Abdulkareem et al.[12] This work presents an experimental investigation of the influence of the three most important machining parameters of depth of cut, feed rate and spindle speed on surface roughness during turning of mild steel. In this study, the design of experiment which is a powerful tool for experimental design is used to optimize the machining parameters for effective machining of the work piece. Box Behnken experimental design method as well as analysis of variance (ANOVA) is used to analyze the influence of machining parameters on surface roughness height Ra.



Fig. 6 3-D plot of effect of cutting speed and spindle speed on Ra.

The 3-dimensional (3-D) response surface plot is also formed based on the quadratic model to evaluate the change in response surface as shown in Fig. 6. The effects of interaction on Ra, is shown in Fig. 6.

The individual parameters effect as well as effect of interactions between the machining parameters on the surface roughness height Ra is analyzed using various graphical representations. Using multiple linear regressions, mathematical models correlating the influence of machining parameters on the surface roughness Ra during the machining process were developed. Confirmation results were used to confirm that mathematical models are good enough to effectively represent machining criteria of surface roughness Ra during the study. The feed rate is found to be the most important parameter effecting Ra, followed by cutting speed while spindle speed has the least effect. Machining with high cutting speed and spindle speed has positive effect on Ra as against feed rate.

#### Conclusions

The developed models using Design of Experiment (DOE) are reasonably accurate and can be used for prediction within limits. Taguchi gives systematic simple approach and efficient method for the optimum operating conditions.

Results show that cutting speed and depth of cut were significant variables to the SR of mild steel. Surface roughness decreases with increase in spindle speed. SR increases with increase in depth of cut. With the increase in feed rate the surface roughness also increases & as the cutting speed decreases the surface roughness increases.

On the flank wear result, cutting speed has significant effect on tool wear. The depth of cut has also have effect on flank wear. It is clear that by reducing the depth of cut, the flank wear can be controlled.

The MRR is increased by increasing any of the process parameters. With the increase in cutting speed the material removal rate is increases & as the feed rate increases the material removal rate is increases. The feed rate has significant influence on both the Cutting force and Surface roughness. Depth of cut has a significant influence on cutting force, but an insignificant influence on surface roughness.

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