International Journal of Mechanical Engineering and Robotics Research

ISSN 2278 – 0149 www.ijmerr.com
Vol. 3, No. 1, January 2014

Review Article

SURFACE QUALITY OPTIMIZATION IN TURNING OPERATIONS USING TAGUCHI METHOD—A REVIEW

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Machining operations have been the core of the manufacturing industry since the industrial revolution. The productivity and quality are two important characteristics those control most of the manufacturing processes. Surface roughness imposes one of the most significant constraints for the selection of cutting parameters and machine tools in development of a process. The optimized parameters of machining are important especially to maximize production rate and to reduce cost. In actual practice, all the factors which affect the surface roughness are classified into tool variables, work piece variables and cutting conditions. To this end, a great deal of research has been performed in order to quantify the effect of various turning process parameters to surface quality. In this paper, an attempt is made to review the optimization of surface roughness in turning operations using Taguchi method, which is being applied successfully in industrial applications for optimal selection of process variables in the area of machining.

Keywords: Optimization, Surface roughness, Turning, Significant constraints, Surface quality

INTRODUCTION

Turning is a versatile and useful machining operation. It is the most important operation and is widely used in most of the manufacturing industries due to its capability of producing complex geometric surfaces with reasonable accuracy and surface finish. In modern industry one of the trends is to manufacture low cost, high quality products in short time. Increasing productivity, decreasing costs, and maintaining high product quality at the same time are the main challenges manufacturing face today (Azouzi and Guillot, 1998). Surface roughness imposes one of the most significant constraints for the selection of cutting parameters and machine tools in development of a process (Abhang and Hameedullah, 2010). It requires attention both from industry personnel as well as in research and development, because this greatly influences machining performances. In

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a manufacturing process it is very important to achieve a consistence tolerance and surface finish (Choudhury and El-Baradie, 1997). Cutting parameters are reflected on surface roughness, surface texture and dimensional deviation turned product. So, there is a need for a tool that should allow the evaluation of the surface roughness value before the machining of the part and which, at the same time, can easily be used in the production floor environment contributing to the minimization of required time and cost and the production of desired surface quality.

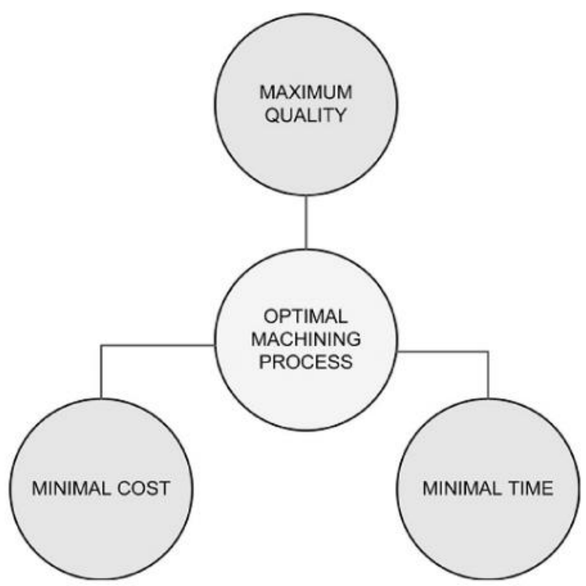
Process optimization is the discipline of adjusting a process to optimize some specified set of parameters without violating some constraint. The most common goals are minimizing cost, maximizing throughout, and/or efficiency. This is one of the major quantitative tools in industrial decision making. Manufacturing industries have long depended on the skill and experience of shop floor machine tool operators for optimal selection of cutting conditions and cutting tools. The most adverse effect of such a not very scientific practice is decreased productivity due to sub optimal use of machining capability. Optimization of machining parameters not only increases the utility for machining economics, but also the product quality to a great extent. In conventional (manual) manufacturing systems, the machined components take only about 6% to 10% of the total available production time on machines being used. By contrast, it has been estimated that the percentage would increase to 65%-80% in modern computer based manufacturing because of the advent of computer based and automated machining systems. This situation makes the need for economic optimization and reliable performance data of machining processes even more pressing than ever before. The surface roughness greatly varies with the change of cutting process parameters. Surface finish in turning has been found to be influenced in varying amounts by a number of factors such as feed rate, work material characteristics, work hardness, unstable built-up edge, cutting speed, depth of cut, cutting time, tool nose radius and tool cutting edge angles, stability of machine tool and work piece setup, chatter, and use of cutting fluids (Palanikumar *et al.*, 2006). That is why proper selection of process parameters is essential along with the prediction of the surface finish (lower Ra value) in turning process.

Modeling of machining processes has attracted the attention of a number of researchers in view of its significant contribution to the overall cost of the product (Merchant, 1998). Measuring surface roughness is vital to quality control of machining work piece. There are problems in attempt to get high quality surface finish of products. For this reason many authors consider the roughness as the fourth dimension of the design (Van Luhervelt *et al.*, 1998). The optimized parameters of machining are important especially to maximize production rate and to reduce cost. Optimized parameters are of great concern in manufacturing environments, where economics of machining operation plays a key role in competitiveness of market, see Figure 1.

It is found that many research works have been done so far on continuous improvement of the performance of turning process. Despite

Taylor's early work on establishing optimum cutting speeds in single pass turnings, progress has been slow since all the process parameters need to be optimized. For realistic solutions, the many constraints met in practice, such as low machine tool power, torque, force limits and component surface roughness must be overcome. The performance of turning is measured in terms of surface finish, cutting forces, power consumed and tool wear. From the era of conventional machine tools to the present era of CNC machine tools, the prediction of cutting behavior of processes and optimization of machining parameters have been hot areas of research. Due to the widespread use of high automated machine tools in industry, manufacturing requires reliable monitoring and optimization. Today the market has an ever changing demand for new products, which require shorter development cycle. An important part of the product development cycle is manufacturing process planning. Shorter process planning time can lead to the use of machining parameters that are not optimal and this can lead to the greater cost of production. A human process planner selects proper machining parameters by using not only his own experience and knowledge but also from handbooks of technological requirements, machine tool, cutting tool and selected part material. This manual selection can be slow and does not have to give optimal results. Figure 1 depicts the possible optimization goals.

Figure 1: Possible Optimization Goals



The latest techniques for optimization, Fuzzy Logic, Scatter Search technique, Ant Colony technique, Genetic Algorithm, Taguchi technique, Response Surface Methodology etc. are being applied successfully in industrial applications for optimal selection of process variables in the area of machining (Shirpurkar *et al.*, 2012). Among these Taguchi Method (Taguchi, 1986) is widely using in industries for making product/process insensitive to any uncontrollable factors such as environmental variables. Through this paper, an attempt is made to review the Taguchi method for optimization of surface roughness in turning operations.

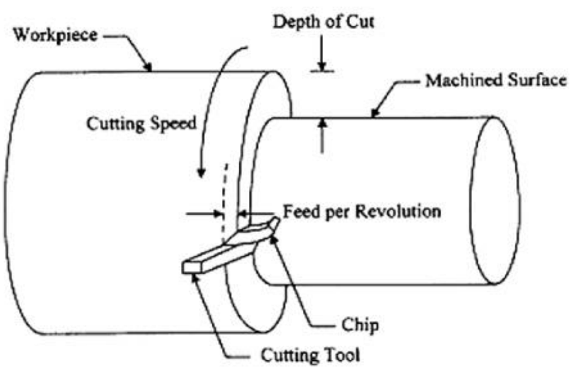
TURNING PROCESS

Turning is the primary process in most of the production activities in the industry. In turning process, a single point cutting tool moves along the axis of a rotating 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. Turning produces rotational, typically axis symmetric parts that have many features, such as holes, grooves, threads, tapers, various diameter steps, and even contoured surfaces.

It can be done manually, in a traditional form of lathe, which frequently requires continuous supervision by the operator, or by using a computer controlled and automated lathe which does not.

Parts that are fabricated completely through turning often include components that are used in limited quantities, perhaps for prototypes, such as custom designed shafts and fastener. Turning is also commonly used as a secondary process to add or refine features on parts that were manufactured using a different process. Due to the high tolerances and surface finishes that turning can offer, it is ideal for adding precision rotational features to a part whose basic shape has already been formed. The peripheral speed of the work piece called cutting speed, movement of the tool along the axis of job for one revolution of job called feed, and radial depth of cut of the tool are the process parameters which are shown in Figure 2. These parameters may be optimized for obtaining the minimum cost of machining and minimum production time. However, for optimization, performance of the process has to be predicted.

Figure 2: Adjustable Parameters in Turning



Source: Choudhury and El-Baradie (1997)

Two main attributes of quality of turned job are surface finish and dimensional deviation. Surface finish is defined as the degree of smoothness of a part's surface after it has been manufactured. Surface finish is the result of the surface roughness, waviness, and flaws remaining on the part. Dimensional deviation is defined as the radial difference between the set depth of cut and the obtained depth of cut. Optimization of cutting parameters is a difficult work (Cus and Balic, 2000), where the following aspects are required knowledge of machining, empirical equations relating the tool life, forces, power, surface finish, etc., to develop realistic constraints, specification of machine tool capabilities, development of an effective optimization criterion and knowledge of mathematical and numerical optimization techniques. Researchers studied the effect of number of factors such as feed rate, cutting speed, depth of cut, work material characterestics, unstable built up edge, tool nose radius, tool angles, stability of material, tool and work piece setup, use of cutting fluids, radial vibration, tool material, etc., on surface finish. The three primary factors in any basic turning operation are speed, feed, and depth of cut. Other factors such as kind of material and type of tool have a large influence, of course, but these three are the ones the operator can change by adjusting the controls, right at the machine. In order to conduct optimization, a mathematical model has to be defined. It is found that many research works have been done so far on continuous improvement of the performance of turning process.

SURFACE ROUGHNESS

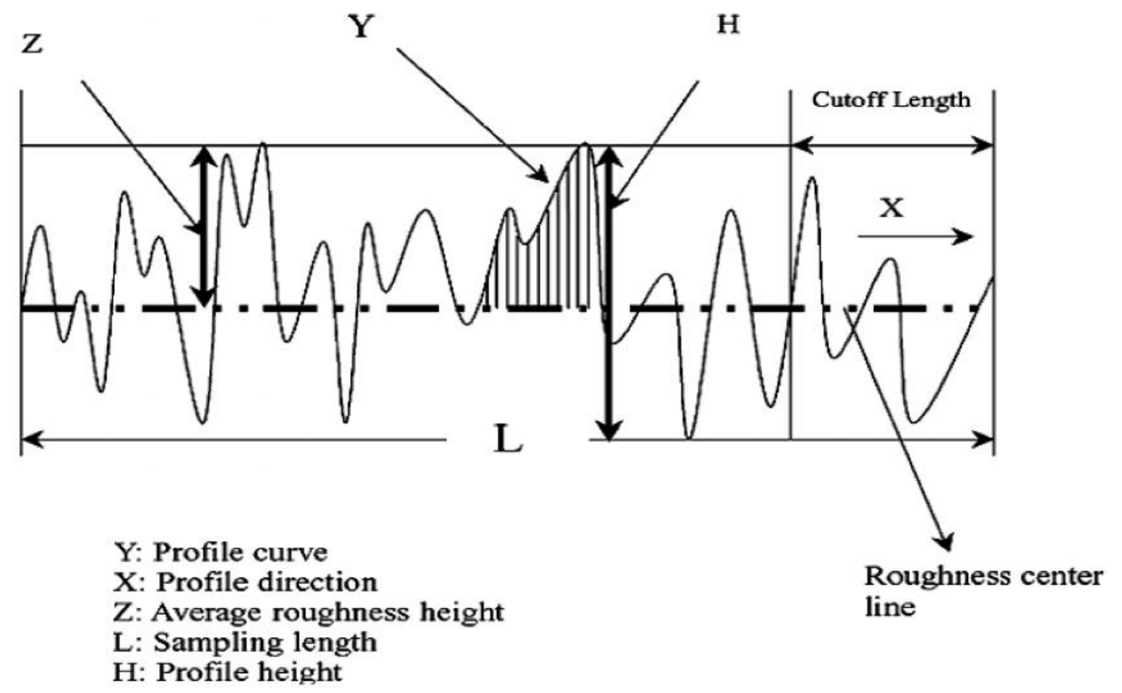
Dimensional accuracy, form stability, surface smoothness, fulfillment of functional requirements in prescribed area of application, etc., are important quality attributes of the product. Optimization of single pass turning has been attempted in early works. However, in general, a turning operation involves a number of rough cuts and a final finish cut. In manufacturing industries, multi pass turning is widely used than single pass turning. The highest possible metal removal is aimed in rough passes, where surface finish is not an important consideration. However, in finish turning process, surface finish is the most important consideration. Surface roughness is termed as the small, finely spaced deviations from nominal surface of the third up to sixth order. Figure 3 shows the surface roughness profile. The average surface roughness is given by,

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

where R_a is the arithmetic average deviation from mean line, L is the sampling length and Y the ordinate of the profile curve (Khalil and Yasir, 2008). Measuring of surface roughness is vital to quality control of machined parts. Measurement of surface roughness of machined work pieces can be carried out by means of different techniques such as, direct measurement, comparison based techniques, noncontact methods, on-process measurement, etc.

Surface finish influences functional properties of machined components such as fatigue strength, wear rate, coefficient of friction, and corrosion resistance of the machined components. The most important parameter describing the surface integrity is surface roughness. Parts such as automobile, aerospace, and medical components need high precision in surface finish. In the

Figure 3: Surface Roughness Profile

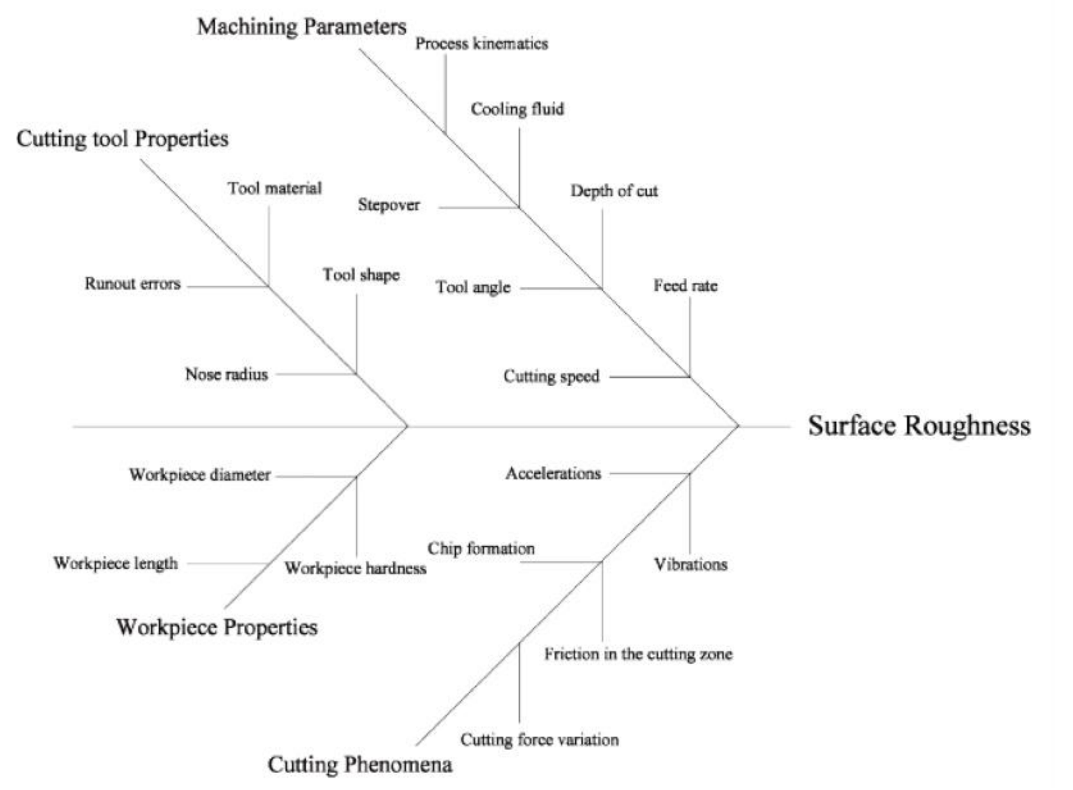


manufacturing industry today, surface must be within certain limits of roughness. The dynamic nature and widespread usage of turning operations in practice have raised a need for seeking a systematic approach that can help to set up turning operations in a timely manner and also to achieve the desired surface quality. Figure 4 shows a fishbone diagram with the parameters that affect surface roughness.

TAGUCHI METHOD—AN OVERVIEW

The Taguchi experimental design method, by Genichi Taguchi is a well-known, unique and powerful technique for product or process quality improvement. It is widely used for analysis of experiment and product or process optimization. Genichi Taguchi is a Japanese engineer who has been active in the improvement of Japan's industrial products and processes 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 tools, especially statistically designed experiments. Taguchi has developed a methodology for the application of factorial design experiments that has taken the design of experiments from the exclusive world of the statistician and brought it more fully into the world of manufacturing. His contributions have also made the practitioner's work simpler by advocating the use of fewer experimental designs, and

Figure 4: Parameters Affecting Surface Roughness



Source: Benardos and Vosniakos (2003)

providing a clearer understanding of the nature of variation and the economic consequences of quality engineering in the world of manufacturing. Taguchi introduces his concepts to:

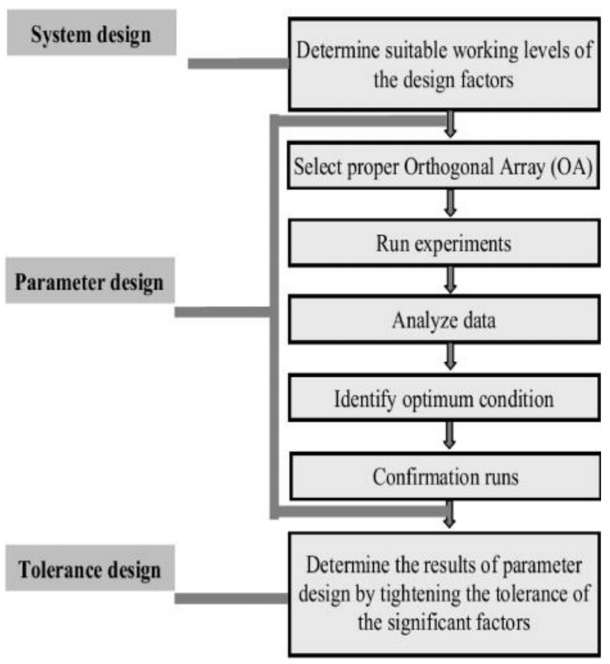
- Quality should be designed into a product and not inspected into it.
- Quality is best achieved by minimizing the deviation from a target.
- Cost of quality should be measured as a function of deviation from the standard and the losses should be measured system wide.

Taguchi recommends a three stage process to achieve desirable product quality by design-system design, parameter design and tolerance design. While system design helps to identify working levels of the design parameters, parameter design seeks to determine parameter levels that provide the best performance of the product or process under study. The optimum condition is selected so that the influence of uncontrollable factors causes minimum variation to system performance. Orthogonal arrays, variance and Signal to Noise analysis are the essential tools of parameter design. Tolerance design is a step to fine tune the results of parameter design (Ross, 1996). Many Japanese firms have achieved great success by applying his methods. Thousands of engineers have performed tens of thousands of experiments based on his teachings (Wu, 1982). Taguchi has received Japan's most prestigious awards for quality achievement, including the Deming prize. In 1986, Taguchi received the most prestigious prize from the International Technology Institute-Willard F Rockwell medal for excellence in technology. Taguchi's major contribution has involved combining engineering and statistical methods to achieve rapid improvements in cost and quality by optimizing product design and manufacturing processes. After Taguchi's association with the top companies and institutes in USA (AT and T) Bell Laboratories, Xerox, Lawrence Institute of Technology (LIT), Ford Motor Company etc.) his methods have been called a radical approach to quality, experimental design and engineering (Barker, 1990). "Taguchi Method" (TM) refers to the parameter design, tolerance design, quality loss function, on line quality control, design of experiments using orthogonal arrays, and methodology applied to evaluate measuring systems. Pignatiello (1988) identifies two separate aspects of the Taguchi methods: the strategy of Taguchi and the tactics of Taguchi. Taguchi tactics refer to the collection of specific methods and techniques used by Taguchi, and Taguchi strategy is the conceptual framework or structure for planning a product or process design experiment. Taguchi addresses design and engineering (off-line) as well as manufacturing (on-line) quality (Benton, 1991). This fundamentally differentiates TM from Statistical Process Control (SPC), which is purely an on-line quality control method.

Taguchi methods represent a new philosophy (Lin *et al.*, 1990). Quality is measured by the deviation of a functional characteristic from its target value. Noises (uncontrolled variables) can cause such deviations resulting in loss of quality. Taguchi methods seek to remove the effect of noises. Taguchi described that quality engineering encompasses all stages of product/process development: system design, parameter design, and tolerance design. The key element for achieving high quality and low cost is parameter design (Byrne and Taguchi, 1987). Through parameter design, levels of product and process factors are determined, such that the product's functional characteristics are optimized and the effect of noise factors is minimized. Parameter design reduces performance variation by reducing the influence of the sources of variation rather than by controlling them, it is thus a very cost effective technique for improving engineering design (Kackar and Shoemaker, 1986). Figure 5 shows Taguchi design procedure (Zhang *et al.*, 2007).

The very intention of Taguchi parameter design is to maximize the performance of a naturally variable production process by modifying the controlled factors (Roy, 2001).

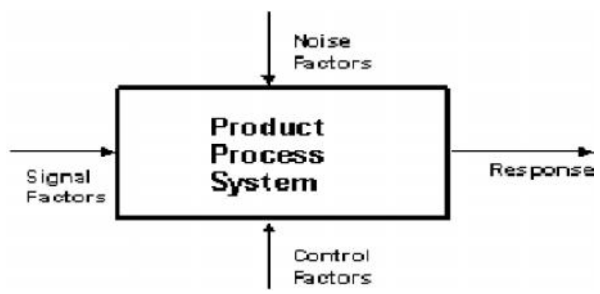
Figure 5: Taguchi Design Procedure



Source: Zhang et al. (2007)

A key idea is the contention that Taguchi parameter design uses the nonlinearity of a response parameter to decrease the sensitivity of the quality characteristic to variability. Figure 6 shows the parameter diagram (P diagram) for a product/process or system. Variability in a manufacturing process can be significant, often uncontrollable, and have varying effects on quality characteristics.

Figure 6: P Diagram



Taguchi's Orthogonal Array (OA) provides a set of well-balanced experiments (with less number of experimental runs) and Taguchi's Signal-to-Noise ratio (S/N), which is logarithmic functions of desired output; serve as objective functions in the optimization process. The S/N ratio is the ratio of the mean (Signal) to the standard deviation (Noise). The standard deviation cannot be minimized first and the mean brought to the target (Kim, 2010). The ratio depends on the quality characteristics of the product/process to be optimized. The standard S/N ratios generally used are as follows: Nominal-is-Best (NB), Lower-the-Better (LB) and Higher-the-Better (HB). Because, irrespective of the quality criteria may be (NB, LB, and HB) S/N ratio should always be maximized. Optimum cutting conditions required for the minimum surface roughness is obtained by using LB criterion. S/N ratio can be obtained from equation,

$S/N = -10 \log 1/n(\Sigma y^2)$ (Hasnul Hadi *et al.*, 2011).

Taguchi method for experimental design is straightforward and easy to apply to many engineering situations with less statistical knowledge. Taguchi method provides a simple, competent and methodical approach to optimize the designs for performance, quality, and cost. It is a method of powerful tool for the design of high quality systems. The methodology is important when the design parameters are qualitative and distinct. Taguchi parameter design can optimize the performance characteristics through the settings of the design parameters and reduce the sensitivity of the system performance to sources of variation. In recent years, the rapid growth of interest in the Taguchi method has led to numerous applications of the method in a world wide range of industries and countries.

The general steps involved in the Taguchi Method are as follows.

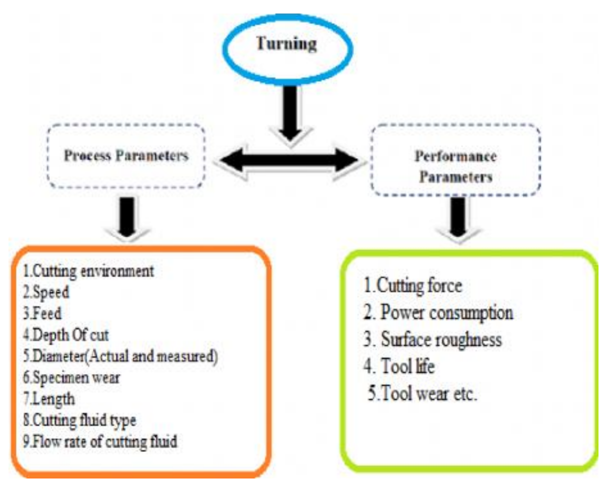
- Define the process objective, or more specifically, a target value for a performance measure of the process. The target of a process may also be a minimum or maximum. The deviation in the performance characteristic from the target value is used to define the loss function for the process.
- Determine the design parameters affecting the process. Parameters are variables within the process that affect the performance measure such as temperatures, pressures, etc. that can be easily controlled. The number of levels that the parameters should be varied must be specified.
- Create Orthogonal Arrays for the parameter design indicating the number of and conditions for each experiment.
- Conduct the experiments indicated in the completed array to collect data on the effect on the performance measure.
- Complete data analysis to determine the effect of the different parameters on the performance measure.
  - Analysis of variance (ANOVA) is a collection of statistical models, and their associated procedures, in which the observed variance in a particular variable is partitioned into components attributable to different sources of variation. ANOVA is used in the analysis of comparative experiments those in which only the difference in outcomes is of interest.
  - The statistical significance of the experiment is determined by a ratio of two variances. This ratio is independent of several possible alterations to the experimental observations: adding a constant to all observations does not alter significance. Multiplying all observations by a constant does not alter significance. So ANOVA statistical significance results are independent of constant bias and scaling errors as well as the units used in expressing observations.

LITERATURE REVIEW

Consideration of machining parameter optimization started out as early as 1907, when (Taylor, 1907) acknowledged the existence of an optimum cutting speed for maximizing material removal rate in single pass turning operations. Research on machining parameter optimization has increased since the 1950's. In 1950 (Gilbert, 1950) presented a theoretical analysis of optimization of machining process and proposed an analytical procedure to determine the cutting speed for a single-pass turning operation with fixed feed rate and depth of cut by using two different objectives (i) maximum production rate and (ii) minimum machining cost. In a review of metal cutting analysis in 1956, Finnie (1956) pointed out- "Despite the large number of attempts, past and present, to analyze metal cutting, a basic relationship between the various variables is still lacking." This remark is valid till today, even after a half century. Nevertheless, the efforts to model machining process are still going on, as the proper understanding of the machining process has a large bearing on the economics of machining. With the advent of capital intensive CNC machine tools, this need has strengthened. An earlier survey for machining aluminum alloy components in the US aircraft industry has shown that the selected cutting speeds were far below the optimal economic speeds. One of the reasons for this poor performance is the lack of predictive models. This has inhibited the widespread use of the available optimization strategies. But, if reliable predictive models for the various technological performance measures are developed, then optimizing the economic performance is feasible, and this can provide a means for bridging the gap between theory and practice.

The prediction of surface roughness, cutting force, and tool life in machining is a challenging task, but is necessary for proper optimization of the process. In actual practice, all the factors which affect the surface roughness are classified into: tool variables, work piece variables and cutting conditions. Tool variables include tool material, nose radius, rake angle, cutting edge geometry, tool vibration, tool overhang, tool point angle, etc. Work piece variables include material, hardness and other mechanical properties. Machining parameters in metal turning are cutting speed, feed rate and depth of cut. The setting of these parameters determines the quality characteristics of turned parts. 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. To this end, a great deal of research has been performed in order to quantify the effect of various turning process parameters to surface quality. Figure 7 shows the process and performance parameters of the turning process. The machining optimization problem is highly nonlinear and possesses multiple

Figure 7: Process and Performance Parameters of Turning



solutions. Researchers considered various input (cutting) parameters like cutting speed, feed rate, depth of cut, cutting time, coolant pressure, etc. Since it can be done at the design stage, Taguchi parameter design allows quality engineers to reduce the need for quality control later (Sriraman, 1996).

Yang and Tang (1998) carried out an experiment consisting of 18 combinations on an engine lathe using tungsten carbide with the grade of P-10 for the machining of S45C steel bars. The cutting parameters that have been selected are cutting speed, feed rate and depth of cut with the response variable, tool life and surface roughness. Results show that for surface roughness, all the cutting parameters have the significant effect. The confirmation experiments then were conducted to verify the optimal cutting parameters. The improvement of tool life and surface roughness from the initial cutting parameters to the optimal cutting parameters is about 250%.

Daniel Kirby (2006) investigated the application of the Taguchi parameter design method to optimize the surface finish in a turning operation of 6061-T6511 Aluminium alloy. In order to meet this purpose in terms of both efficiency and effectiveness, this study utilizes the Taguchi parameter design methodology. This includes selection of parameters, utilizing an orthogonal array, conducting experimental runs, data analysis, determining the optimum combination, and verification. Controlled factors include spindle speed, feed rate, and depth of cut; and the noise factor is slightly damaged jaws. Table 1 shows the parameters and levels for this experimental design. The noise factor is included to increase the robustness and applicability of this study. The array selected to meet these criteria is a modified L8 array. In this study he concluded that feed rate had the highest effect on surface roughness, spindle speed had a moderate effect, and depth of cut had an insignificant effect.

Table 1: Parameters and Levels for Experimental Design

Controlled Parameters	ID	Level 1	Level 2	Level 3	Level 4
Feed rate, f (in/rev)	A	0.002	0.003	0.004	0.005
Spindle speed, N (rev/min)	B	2500	3500		
Depth of cut, d (in)	C	0.010	0.020		

Source: Daniel Kirby (2006)

Thamizhmanii *et al.* (2007) applied Taguchi method for finding out the optimal value of surface roughness under optimum cutting condition in turning SCM 440 alloy steel. The experiment was designed by using Taguchi method and experiments were conducted and results thereof were analysed with the help of ANOVA. The causes of poor surface finish as detected were machine tool vibrations, tool chattering whose effects were ignored for analysis. The authors concluded that the results obtained by this method would be useful to other researches for similar type of study on tool vibrations, cutting forces etc. The work concluded that depth of cut was the only significant factor which contributed to the surface roughness. Sahoo *et al.* (2008) studied for optimization of machining parameters combinations emphasizing on fractal characteristics of surface profile generated in CNC turning operation. The authors used L27 Taguchi Orthogonal Array design with machining parameters: speed, feed and depth of cut on three different work piece materials viz., aluminium, mild steel and brass. It was concluded that feed rate was more significant influencing surface finish in all three materials. It was observed that in case of mild steel and aluminium feed showed some influences while in case of brass depth of cut was noticed to impose some influences on surface finish. The factorial interaction was responsible for controlling the fractal dimensions of surface profile produced in CNC turning.

Philip Selvaraj and Chandramohan (2010) presents the influence of cutting parameters like cutting speed, feed rate and depth of cut on the surface roughness of austenitic stainless steel during dry turning. A plan of experiments based on Taguchi technique has been used to acquire the data. An Orthogonal Array, S/N ratio and the Analysis of Variance (ANOVA) are employed to investigate the cutting characteristics of AISI 304 austenitic stainless steel bars using TiC and TiCN coated tungsten carbide cutting tool. The parameters selected are speed (80, 100, 120 m/min), feed (0.08, 0.1, 0.12 mm/rev) and depth of cut (0.4, 0.6, 0.8 mm). In this study, Taguchi Orthogonal Array, the Signal to Noise (S/N) ratio and the analysis of variance (ANOVA) were used for the optimization of cutting parameters. ANOVA results shows that feed rate, cutting speed and depth of cut affects the surface roughness by 51.84%, 41.99% and 1.66% respectively. A confirmation experiment verified the effectiveness of the Taguchi optimization method which is evident from Table 2.

Table 2: Results of the Confirmation Experiment for Surface Roughness

	Predicted Parameters	Experimental Parameters
Level	A2B1C1	A2B1C1
Surface roughness (µm)	0.65	0.61
S/N ratio	3.73	4.29

Source: Philip Selvaraj and Chandramohan (2010)

Venkata Ramana *et al.* (2011) investigated the performance evaluation and optimization of process parameters in turning of Ti6Al4V alloy with different coolant conditions using Taguchi design of experiments methodology on surface roughness, by uncoated carbide tool. The results have been compared among dry, flooded with servo cut oil and water and flooded with synthetic oil coolant conditions and optimum is found out which is shown in Table 3. From the experimental investigations, the cutting performance on Ti6Al4V alloy with synthetic oil is found to be better when compared to dry and servo cut oil and water in reducing surface roughness. The results from ANOVA shows that while machining Ti6Al4V alloy, the synthetic oil is more effective under high cutting speed, high depth of cut and low feed rate compared to dry and servo cut oil and water conditions. The ANOVA also reveals that feed rate is dominant parameter under dry, servo cut oil and water and synthetic oil conditions in optimizing the surface roughness.

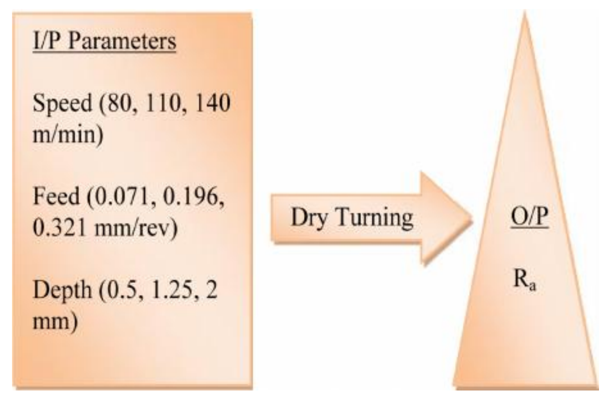
Table 3: Optimum Parameters

Lubricating Conditions	Speed (rpm)	Feed (mm/min)	Depth of Cut (mm)
Dry	400	0.206	0.6
Servo cut oil+ Water	500	0.240	1
Synthetic oil	630	0.329	1.6

Source: Venkata Ramana et al. (2011)

Marinkovic Velibor and MadicMilos (2011) investigated the modelling and optimization of surface roughness in dry single point turning of cold rolled alloy steel 42CrMo4/AISI 4140 using TiN-coated tungsten carbide inserts. Figure 8 shows the cutting factors and their

Figure 8: Dry Turning of 42CrMo4/AISI 4140

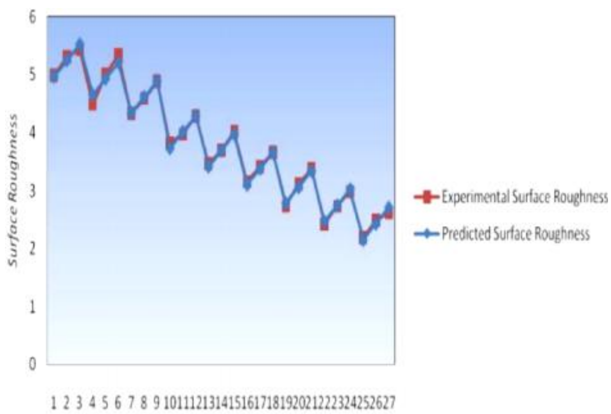


Source: Marinkovic Velibor and MadicMilos (2011)

levels used for this study. Each of the other parameters was taken as constant. The average surface roughness was chosen as a measure of surface quality. The experiment was designed and carried out on the basis of standard L27 Taguchi orthogonal array. The data set from the experiment was employed for conducting the optimization procedures, according to the principles of the Taguchi method. The results of calculations were in good agreement with the experimental data. The results confirm the effectiveness of Taguchi technique in optimization of cutting processes. On the basis of the experimental results and derived analysis, concluded that cutting speed has the most dominant effect on the observed surface roughness, followed by feed rate and depth of cut, whose influences on surface roughness are smaller. The surface roughness is continuously improved with the increase in cutting speed, but increase in feed rate and depth of cut causes a significant deterioration of surface roughness. The results obtained using the Taguchi optimization method revealed that the cutting speed should be kept at the highest level, while both feed rate and depth of cut should be kept at the lowest level to get minimum roughness.

Adarsh Kumar *et al.* (2012) conducted the analysis of optimum cutting conditions to get lowest surface roughness in facing by regression analysis. They conducted an experimental study to investigate the effects of cutting parameters like spindle speed, feed and depth of cut on surface finish on EN-8. The levels of parameters selected are speed (100, 360, 560rpm), feed (0.14, 0.15, 0.16 mm/rev) and depth of cut (0.5, 1, 1.5 mm). Multiple regression modelling was performed to predict the surface roughness by using machining parameters. Machining was done using cemented carbide insert. Mitutoyo SJ-310 for surface roughness tester is used for roughness readings. It was seen that the effect of feed rate is greater than the effect of cutting speed and to improve the surface roughness, a good combination of cutting speed and feed rate needs to be selected. The feed has the variable effect on surface roughness. Figure 9 shows the comparison of experimental and predicted surface roughness reveals the

Figure 9: Comparison of Experimental and Predicted Surface Roughness



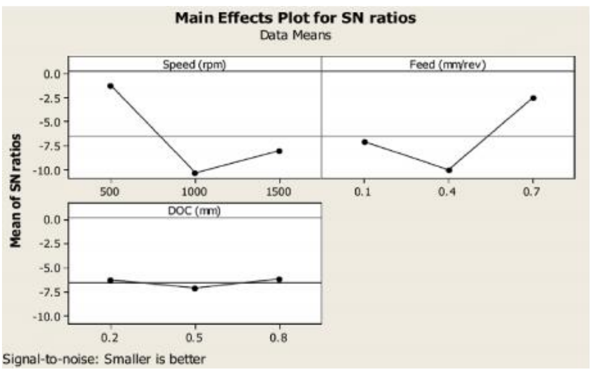
Source: Marinkovic Adarsh Kumar et al. (2012)

validity of the experiment. The relationship between feed rate and surface roughness is proportional, increasing the feed rate, increases the surface roughness. On surface roughness, the effect of feed rate is more considerable than cutting speed.

Somashekara and Lakshmana Swamy (2012) investigated optimization of surface roughness in turning operation using Taguchi technique and ANOVA. The objective of the study is to obtain an optimal setting of turning parameters (cutting speed, feed and depth of cut) which results in an optimal value of surface roughness while machining Al 6351-T6 alloy with uncoated carbide inserts. The machining condition parameters were the cutting speed of 500, 1000 and 1500 rpm, feed rate of 0.1, 0.4 and 0.7 mm/rev, while the Depth Of Cut (DOC) as 0.2, 0.5 and 0.8 mm. From the results obtained a regression model has been developed for surface roughness as,

Ra (µm) = 1.69 + 0.00146 Speed (rpm) – 1.92 Feed (mm/rev) + 0.24 DOC (mm). From this equation one can predict the value of surface roughness if the values of cutting speed, feed and depth of cut are known. Figure 10 shows S/N ratio values for surface roughness. From ANOVA and response table for Signal to Noise ratios, it can be concluded that speed has a greater influence on the surface roughness followed by feed. Depth of cut has least influence on surface roughness.

Figure 10: S/N Ratio Values for Surface Roughness



Source: Somashekara and Lakshmana Swamy (2012)

Sreenivasa Murthy *et al.* (2013) in their work envisage the optimal setting of process parameters which influences the surface roughness during the machining operation of EN41B alloy steel with cermet tool. Experiments have been carried out using Taguchi design. The surface roughness is considered as quality characteristic while the process parameters considered are speed, feed and depth of cut. Table 4 shows the ranking of cutting parameters selected by ANOVA. Regression equation for surface roughness is obtained using MINITAB 16 as $Ra = e^{3.02}\ S^{0.068}\ f^{0.874}\ d^{0.074}$. The results of machining experiments were used to characterize the main factors affecting surface roughness by the Analysis of Variance. The feed and speed are identified as the most influential process parameters on work piece surface roughness. The ANOVA and F-test revealed that feed is the dominant parameter followed by speed for surface roughness.

Ballal Yuvaraj *et al.* (2012) carried out turning of grey cast iron using Taguchi method. They describe use and steps of Taguchi design

Table 4: Ranking of Cutting Parameters

Level	Speed	Feed	Depth of Cut
1	2.786	2.006	2.552
2	2.236	2.266	2.635
3	2.855	3.544	2.689
Rank	2	1	3

Source: Sreenivasa Murthy et al. (2013)

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 FG 260 gray cast iron material. Three parameters namely feed rate, spindle speed and depth of cut are varied to study their effect on surface finish, tool wear and MRR. They carried work on simple turn 5075 CNC lathe with CNMA 120408 as a tool material with Minitab software for effect analysis. They selected L27 orthogonal array for taguchi design. It is a scientifically disciplined mechanism for evaluating and implementing improvements in products, processes, materials, equipment's and facilities.

Neseli *et al.* (2011)] investigated the influence of tool geometry on the surface finish obtained in turning of AISI 1040 steel with Al_2O_3/TiC tool. The results indicated that the tool nose radius was the dominant factor on the surface roughness with 51.45% contribution in the total variability of model. Kilickap *et al.* (2005) investigated tool wear and surface roughness in machining of homogenized SiC-p reinforced Aluminium metal matrix composite using Taguchi method. They found that surface roughness is influenced with cutting speed and feed rate. Higher cutting speed and lower feed rates produced better surface quality.

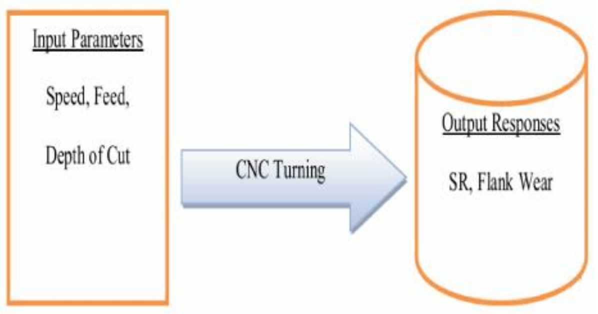
Kassab and Khoshnaw (2007) examined the correlation between surface roughness and cutting tool vibration for turning operation. The process parameters were cutting speed, depth of cut, feed rate and tool overhanging. The experiments were carried out on lathe using dry turning operation of medium carbon 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.

Kamaraj Chandrasekaran *et al.* (2012) carried out CNC turning on AISI410 with single and nano multilayered carbide tools coated with multilayered TiCN + Al_2O_3, multilayered Ti (C, N, B), single layered (Ti, Al) N, and nano multilayered B-Tic under dry conditions. Different cutting parameters, namely, cutting speed, feed rate, and depth of the cut are used for the optimal setting of the parameters. Experiments were carried out using the Taguchi's L27 orthogonal array. The effect of cutting parameters on Surface Roughness (SR) was evaluated and optimal setting conditions were determined for minimization of SR. Analysis of Variance (ANOVA) was used for identifying the significant parameters affecting the response. They concluded from the results of ANOVA, the feed rate and cutting speed are the significant cutting parameters affecting the SR with Ti (C, N, B), (Ti,Al) N, and B-Tic, the feed rate and depth of cut are the significant cutting parameters affecting the SR with TiCN + Al_2O_3, a minimum SR value was obtained using multilayered B-Tic carbide tools rather than TiCN + Al_2O_3 (C,N,B) and (Ti,Al)N.

Yanda *et al.* (2010) carried out optimization of material removal rate, surface roughness and tool life on conventional dry turning of ductile cast iron FCD700 grade using TiN coated cutting tool. The machining parameters were the cutting speed (220, 300, 360 m/min), feed rate (0.2, 0.3, 0.5 mm/rev) while the Depth Of Cut (DOC) was kept constant at 2 mm. The effect of cutting condition (cutting speed and feed rate) on MRR, surface roughness, and tool life were studied and analysed. Experiments were conducted based on the Taguchi design of experiments (DOE) with orthogonal L9 array, and then followed by optimization of the results using ANOVA. Low surface finish was obtained at high cutting speed and low feed rate.

Senthilkumaar *et al.* (2010) carried out the analysis of surface roughness and flank wear in finish turning and facing of Inconel 718 using Taguchi technique. Single pass finish turning and facing operations were conducted in dry cutting condition using uncoated carbide tools. The experiments were conducted on the L16 ACE designer CNC lathe. Uncoated carbide inserts as per ISO specification SNMG 120408-QM H13A were clamped onto a tool holder with a designation of DSKNL 2020K 12 IMP for facing operation and DBSNR 2020K 12 for turning operation. Cutting experiments were conducted as per the full factorial design under dry cutting conditions. The machining parameters and performance measures were shown in Figure 11. Based on Taguchi design of experiments and non-linear regression analysis, the cutting speed is found as the main factor that has highest influence on surface roughness as well as flank wear of turning and facing processes. The percentage error between experimental and predicted result is 8.69% and 8.49% in turning and facing process respectively. Based on the analysis cutting speed and depth of cut are found as the dominant factors.

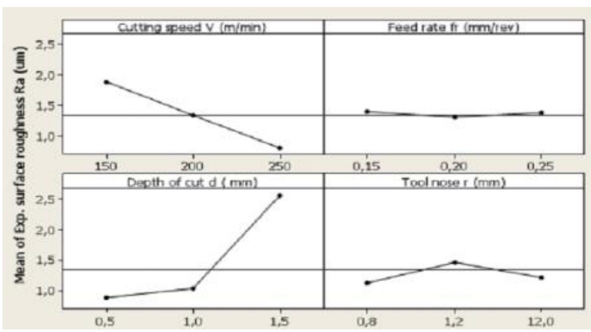
Figure 11: CNC Turning of Inconel 718



Source: Senthilkumaar et al. (2010)

Basim Khidhir and Bashir Mohamed (2011) performed CNC turning on Nickel based Hastelloy C-276 using two different inserts of ceramic cutting tools. The influences of cutting speed, tool inserts type and work piece material were investigated on the machined surface roughness. Cutting speed was found to have a significant effect on the machined surface roughness values. Figure 12 shows

Fig.12. Main Effects Plot for Surface Roughness



Source: Basim Khidhir and Bashir Mohamed (2011) the main effects plot for surface roughness. Round insert found to produce better surface roughness associated with decreasing the depth of cut and increasing the cutting speed.

Mustafa Gunaya and Emre Yucel (2012) investigated the cutting conditions for the average surface roughness (Ra) obtained in machining of high alloy white cast iron (Ni-Hard) at two different hard-ness levels (50 HRC and 62 HRC). Machining experiments were performed at the CNC lathe using ceramic and Cubic Boron Nitride (CBN) cutting tools on Ni-Hard materials. Cutting speed, feed rate and depth of cut were chosen as the cutting parameters. Table 5 shows the variables and their levels used in this work. Taguchi L18 Orthogonal Array was used to design of experiment. Optimal cutting conditions was determined using the Signal-to-Noise (S/N) ratio which was calculated for Ra according to the-smaller-the-better approach. The effects of the cutting parameters and tool materials on surface roughness were evaluated by ANOVA. The statistical analysis indicated that the parameters that have the biggest effect on Ra for Ni hard materials with 50 HRC and 62 HRC are the cutting speed and feed rate, respectively.

Bouacha *et al.* (2010) investigated the roughness values created in hard turning of 64 HRC hardness AISI 52100 bearing steel with CBN cutting tool. They performed the machining tests according to the L27 orthogonal array of Taguchi experimental design method. They reported that the cutting parameter which is the most effective on Ra is the feed rate and cutting speed.

Table 5: Variables and Levels

Variables	Level 1	Level 2	Level 3
A-Cutting tool	Ceramic	CBN	-
B-Cutting speed (m/min)	50	100	150
C-Feed rate (mm/rev)	0.05	0.075	0.1
D- Depth of cut (mm)	0.25	0.5	0.75

Source: Davim and Figueira (2007)

Davim and Figueira (2007) investigated the machinability of a cold work tool steel which is hardened to 60 HRC by turning. In the end of the experiments performed according to Taguchi L27 Orthogonal Array they found that Ra value decreases by the increasing cutting speed.

Aslan *et al.* (2007) evaluated the Ra and cutting tool wear during the machining of AISI 4140 (63 HRC) steel by an experiment using Al_2O_3 + TiCN cutting tool according to Taguchi L27 Orthogonal Array. The experimental parameters chosen were speed, feed and depth of cut. They reported according to the ANOVA results that the effect of cutting speed on the tool wear is 30%. The surface roughness increased as the speed increases. They suggested 250 m/min cutting speed, 0.25 mm depth of cut and 0.05 mm/rev feed rate to minimize the Ra value.

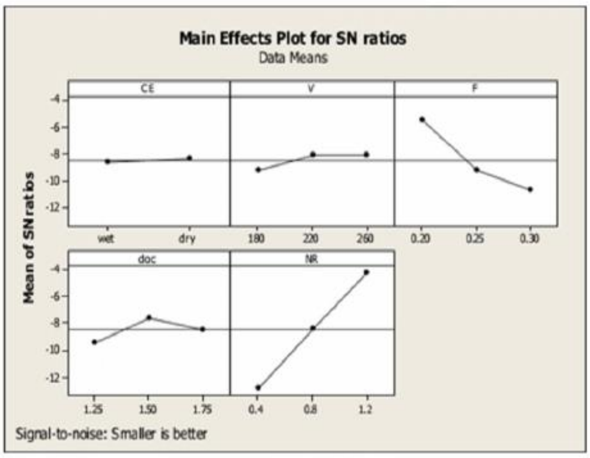
Asilturk and Akkus (2011) investigated the use of the Taguchi method for minimizing the average surface roughness (Ra) and the arithmetic mean value of the single roughness depths of consecutive sampling lengths (Rz) in turning of hardened AISI 4140 (51 HRC) with coated carbide cutting tools. Taguchi Orthogonal and Signal-to-Noise ratios (S/N) are used as objective functions in optimization process. Their study focused on effects of cutting speed, feed rate and depth of cut on surface roughness. Statistical analysis of experimental data indicated that the feed rate has the most significant effect on Ra and Rz. The authors were also found that the optimum cutting conditions was different for Ra and Rz.

Mahendra Korat and Neeraj Agarwal (2012) investigated the effects of the process parameters viz., coolant condition, cutting speed, feed, depth of cut, nose radius, on response characteristics viz., material removal rate, surface roughness, on EN24 material in CNC turning. The tungsten carbide inserts used were of ISO coding TNMG 160404, TNMG 160408 and TNMG 160412 and tool holder of ISO coding ETJNL2525M16. Analysis of Variance suggests that the nose radius is the most significant factor and cutting environment is most insignificant factor for both surface roughness and MRR. ANOVA results shows that nose radius, feed rate, depth of cut, cutting speed and coolant condition affects the surface roughness by 65.38%, 25.15%, 3.06%, 1.41% and 0.09% respectively. Figure 13 shows the effect of process parameters on surface roughness.

Kacal and Gulesin (2011) optimized the machining parameters in finish turning of austempered cast iron GJS-400-15 according to the L18 Orthogonal Array of Taguchi. ANOVA results revealed that feed rate is the most effective parameter for surface roughness. The optimum cutting conditions found for Ra as: 290 °C austempering temperature, ceramic tool, 800 m/min cutting speed and 0.05 mm/rev feed rate.

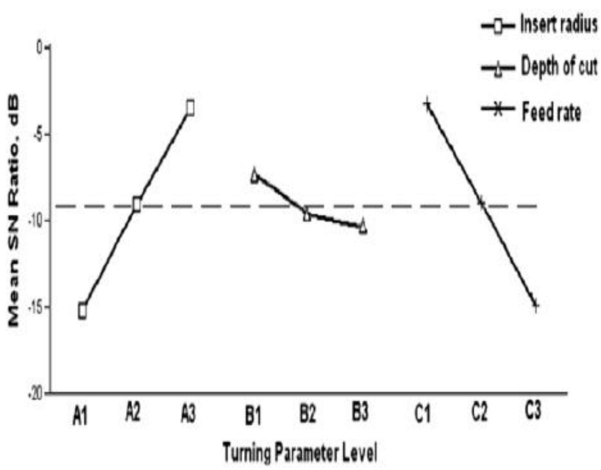
Nalbant *et al.* (2007) in their study used Taguchi method to find the optimal cutting parameters for surface roughness in turning. The Orthogonal Array, the Signal-to-Noise ratio, and ANOVA are employed to study the performance characteristics in turning operations of AISI 1030 steel bars using TiN coated tools. Three cutting parameters namely, insert radius, feed rate, and depth of cut, are optimized with consideration of surface roughness. Figure 14 shows Signal to-Noise graph for surface roughness. The experimental results demonstrate that the insert radius and feed rate are the main parameters among the

Figure 13: Effect of Process Parameters on Surface Roughness



Source: Mahendra Korat and Neeraj Agarwal (2012)

Figure 14: Signal-to-Noise Graph for Surface Roughness



Source: Nalbant et al. (2007)

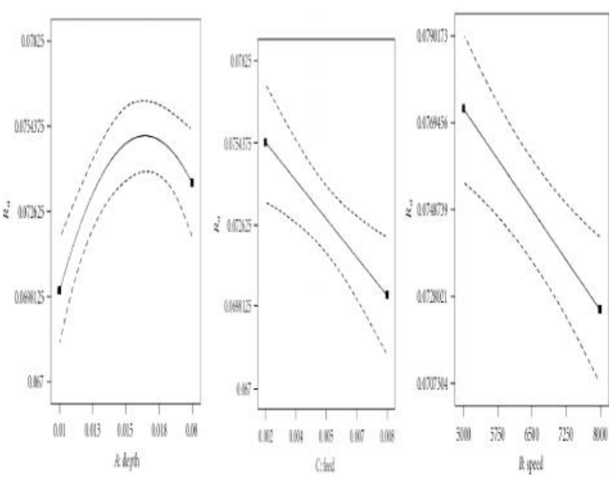
three controllable factors (insert radius, feed rate and depth of cut) that influence the surface roughness. The percentage contributions of insert radius, feed rate and depth of cut are 48.54, 46.95 and 3.39, respectively. It is found that the parameter design of the Taguchi method provides a simple, systematic, and efficient methodology for the optimization of the cutting parameters.

Anirban Bhattacharya *et al.* (2009) have investigated the effect of cutting parameters on surface finish and power consumption during high speed machining of AISI 1045 steel using Taguchi design and ANOVA. The result showed a significant effect of cutting speed on surface roughness and power consumption, while the other parameters have not substantially affected the response.

Lan and Wang (2009) used Orthogonal Array of Taguchi method coupled with Grey Relational Analysis considering four parameters viz. speed, cutting depth, feed rate, tool nose run off etc. for optimizing three responses: surface roughness, tool wear and material removal rate in precision turning on an ECOCA-3807 CNC lathe. The MINITAB software was explored to analyse the mean effect of Signal-to-Noise (S/N) ratio to achieve the multi objective features. This study not only proposed an optimization approach using Orthogonal Array and Grey Relational Analysis but also contributed a satisfactory technique for improving the multiple machining performances in precision CNC turning with profound insight.

Kandananond (2009) investigated the cutting conditions for minimizing surface roughness in a turning process of ferrite stainless steel, grade AISI 12L14. The work pieces used were the sleeves of Fluid Dynamic Bearing (FDB) spindle motors manufactured in the final assembly department at a factory which supplies FDB motors for hard disk drives. The effects of the depth of cut, spindle speed and feed rate on surface roughness were studied using the Taguchi design. The ANOVA shows that all three factors and the interactions depth of cut, spindle speed, feed rate have significant effects on the response. Figure 15 shows surface roughness Ra versus depth of cut, feed and speed graphs.

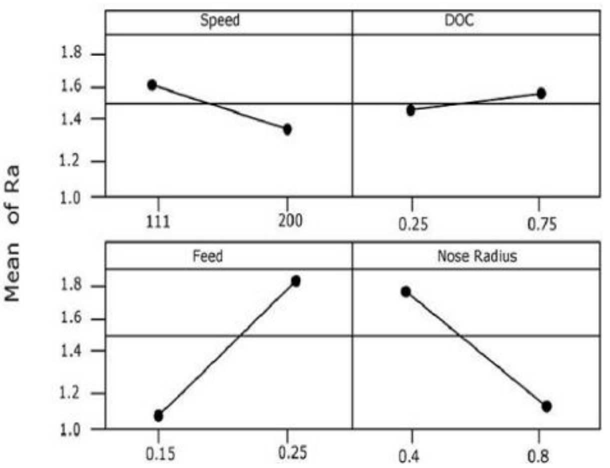
Figure 15: Ra versus Depth of Cut, Feed and Speed



Source: Kandananond (2009)

Kaladhar *et al.* (2012) deals with the 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 CNC lathe. Further, the ANOVA was used to analyse the influence of process parameters and their interaction during machining. Figure 16 shows the main effects plot for surface roughness. From the analysis, it is observed that the feed is the most significant factor that influences the surface roughness followed by nose radius. An attempt has been made to generate to prediction models for surface roughness. The predicted values are confirmed by using validation experiments.

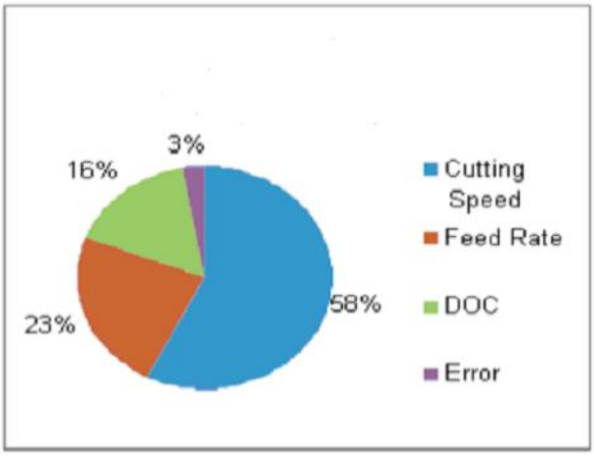
Figure 16: Main Effects Plot for Surface Roughness



Source: Kaladhar et al. (2012)

Jitendra Verma (2012) focused on the analysis of optimum cutting conditions to get lowest surface roughness in turning ASTM A242 Type 1 alloy steel using universal turning machine tool by Taguchi method. 9 experiments were conducted by this process. The results are analysed using Taguchi method. ANOVA has shown that the cutting speed has significant role to play in producing lower surface roughness about 58% followed by feed rate about 23% which is shown in Figure 17. The depth of cut has lesser role on surface roughness from the tests.

Figure 17: % Contribution for Surface Roughness

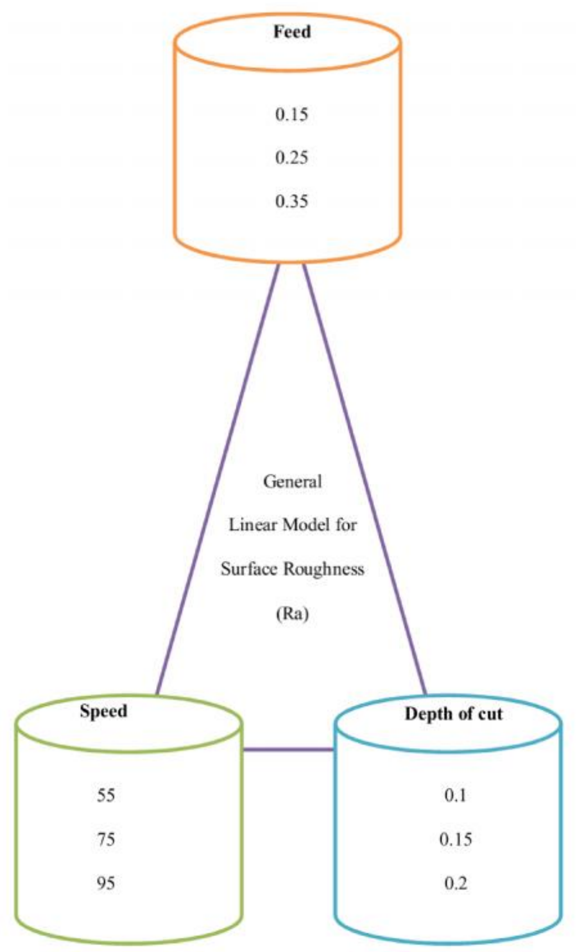


Source: Jitendra Verma (2012)

Akhyar *et al.* (2008) elaborates Taguchi optimization methodology is applied to optimize cutting parameters in turning Ti6Al4V extra low interstitial with coated and uncoated cemented carbide tools under dry cutting condition and high cutting speed. The turning parameters evaluated are cutting speed of 55, 75, and 95 m/min, feed rate of 0.15, 0.25 and 0.35 mm/rev, depth of cut of 0.10, 0.15 and 0.20 mm and tool grades of K313, KC9225 and KC5010, each at three levels. The significant factors for the surface roughness in turning Ti6Al4V ELI were the feed rate and the tool grade, with contribution of 47.146% and 38.881%, respectively. The general linear model for analysis of variance is presented in Figure 18.

Kopac *et al.* (2002) considered cutting speed, tool materials, feed rate and depth of cut as cutting parameters in machining C15 E4 steel on a lathe. They used Taguchi Orthogonal Array of L16, which has two levels and a degree of freedom of 13 in the experimental design. They reported that the

Figure 18: General Linear Model for ANOVA

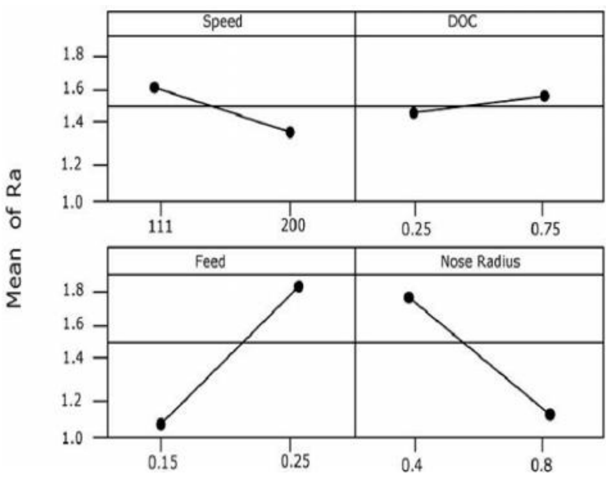


Source: Akhyar et al. (2008)

cutting parameter which is most effective on Ra is the cutting speed and better surface roughness is obtained at higher cutting speeds.

Lazarevic *et al.* (2012) discusses the use of Taguchi method for minimizing the surface roughness in turning polyethylene. The influence of four cutting parameters, cutting speed (65.03, 115.61, 213.88 m/min),feed rate (0.049, 0.098, 0.196 mm/rev), depth of cut (1,2,4 mm) and tool nose radius (0.4,0.8 mm) on average surface roughness (Ra) was analyzed on the basis of the standard L27 Taguchi orthogonal array. The experimental results were then collected and analyzed with the help of the commercial software package MINITAB. Based on the analysis of means (ANOM) and analysis of variance (ANOVA), the optimal cutting parameter settings are determined, as well as level of importance of the cutting parameters. ANOVA results indicate that the feed rate is far the most significant parameter, followed by tool nose radius, and cutting speed, whereas the influence of depth of cut is negligible. Figure 19 shows % contribution for surface roughness. The ANOVA resulted in less than 10% error indicating that the interaction effect of process parameters is small. The optimum levels of the process parameters for minimum surface roughness are as follows: cutting speed –213.88 m/min, feed rate –0.049 mm/rev, depth of cut –2 mm, and tool nose radius –0.8 mm. The machine used for the experiments was the universal lathe machine Potisje PA-C30. Cutting tool was SANDVIK coromant tool

Figure 19: % Contribution for Surface Roughness

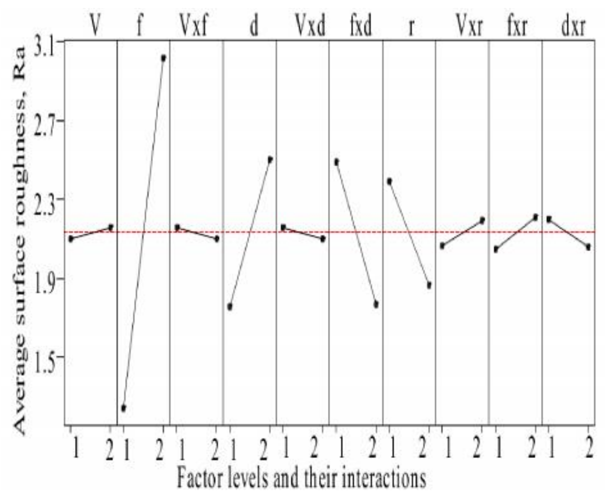


Source: Lazarevic et al. (2012)

holder SVJBR 3225P 16 with inserts VCGX 16 04 04-AL (H10) and VCGX 16 04 08-AL (H10). It was measured at three equally spaced positions around the circumference of the work piece using the profilometer Surftest Mitutoyo SJ-301.

Ali Riza Motorcu (2010) investigated the surface roughness in the turning of AISI 8660 hardened alloy steels by ceramic based cutting tools was in terms of main cutting parameters such as cutting speed, feed rate, depth of cut in addition to tool nose radius, using a statistical approach. Machining tests were carried out with PVD coated ceramic cutting tools under different conditions. An Orthogonal Array, Signal-to-Noise ratio and Analysis of Variance were employed to find out the effective cutting parameters and nose radius on the surface roughness. The machine used for the turning tests was a John ford TC35 industrial type of Computer Numeric Control (CNC) lathe machine. The insert was coated using a PVD method. The coating substance took place on the mixed ceramic substrate and PVD-TiN coated mixed ceramic with a matrix of Al2O3 (70%): TiC (30%) +TiN. The insert types were SNGA 120408 and SNGA 120412. AISI 8660 is a high carbon, chromium-nickel-molybdenum alloy steel with high hardness and strength and is suitable for springs and axle shafts. The work pieces were in the form of cylinders of 52 mm diameter and 220 mm length. The standard heat treatment process to specimens was applied under water condition and the average hardness measured was about 50 HRC. These bars are machined under dry condition. The equipment used for measuring the surface roughness was a surface roughness tester, MAHR Perthometer-M1 type of portable. The surface roughness measures used is the arithmetic mean deviation of the surface roughness of profile, Ra. In collecting the surface roughness data of the shaft with the surface profilometer, three measurements were taken along the shaft axis for each sample with the measurements being about 120° apart. Figure 20 shows factor levels and their interactions on Ra.

Figure 20: Factor Levels and Their Interactions on Ra



Source: Lazarevic et al. (2012)

The obtained results indicate that the feed rate was found to be the dominant factor among controllable factors on the surface roughness, followed by depth of cut and tool's nose radius. However, the cutting speed showed an insignificant effect. Furthermore, the interaction of feed rate/depth of cut was found to be significant on the surface finish due to surface hardening of steel. Moreover, the second order regression model also shows that the predicted values were very close to the experimental one for surface roughness.

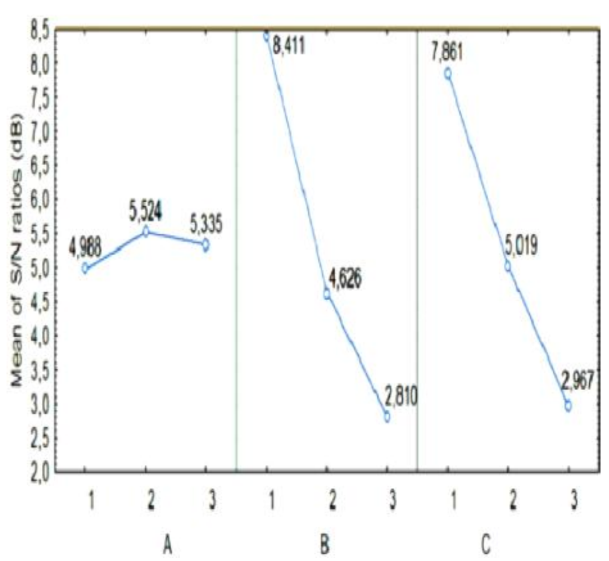
Salvi *et al.* (2013) focused on hard turning of 20 MnCr5 Steel. The purpose of this paper is to analyze optimum cutting conditions to get lowest surface roughness in turning of 20 MnCr5 Steel. Taguchi method has been used for this. Table 6 shows the parameters and their levels used for the experiment. An Orthogonal array, the signal to noise ratio and analysis of variance (ANOVA) are employed to investigate the cutting characteristics. The cutting insert used is ceramic based TNGA 160404. ACE Jobber Jr.lathe machine was used to test cut the hardened material. Taylor Hobson Surtronic 3+ portable surface profilometer is used to measure surface roughness of the work piece machine during experiment. The cutting tool (insert) used for this experiment is supplied by Sandwich. The insert used is TNGA160404. It is a ceramic based cutting tool. Cutting tool is ideal for finishing to general machining of most work piece materials at higher speeds. It was placed on a right-hand tool holder with a designation of MCLNR 2525M12. The results indicate that feed rate has significant role to play in producing lower surface roughness followed by cutting speed. When the feed speed increases the Ra values also increases.

Table 6: Parameters and Their Levels

Parameters	Level 1	Level 2	Level 3
Speed (m/min)	290	175	232.5
Feed (mm/rev)	0.25	0.15	0.2
Depth of Cut (mm)	0.4	0.07	0.23

Franko Puh *et al.* (2012) applied Taguchi method to find optimum process parameters for hard turning of hardened steel AISI 4142 using PCBN tool. Orthogonal design (L9), Signal-to-Noise ratio and Analysis of Variance (ANOVA) are applied to study performance characteristics of cutting parameters (cutting speed, feed and depth of cut) with consideration of surface roughness. Significant factors affecting surface roughness were identified, and the optimal cutting combination was determined by seeking the best surface roughness (response) and S/N ratio. Using multiple regression the exponential, first order linear and second order prediction models were obtained to find the correlation between surface roughness and independent variables. Finally, confirmation tests verified that the Taguchi design was successful in optimizing turning parameters for surface roughness. Figure 21 shows Signal-to-Noise graph for parameters. Cutting speed had insignificant influence on surface roughness. The contributions are in the following order: feed rate (56.736%), depth of cut (41.86%) and then cutting speed (0.214%). The estimated ratio and were calculated using the optimal cutting parameters for surface roughness.

Figure 21: Signal-to-Noise Graph for Parameters



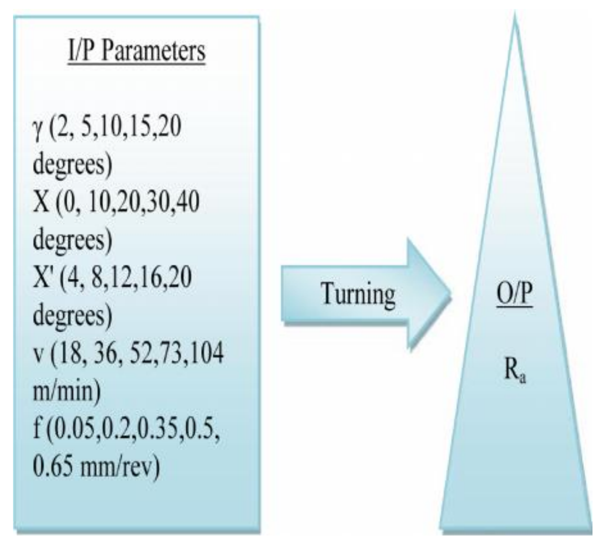
Source: Franko Puh et al. (2012)

(Salvi et al. (2013)

The confirmation experiment was conducted and verified the optimal cutting parameters. The mean result of the confirmation test at the optimum condition is within confidence interval (0.257-0.294) μm. The experiment is considered satisfactory when the mean result falls within this limit. The improvement of surface roughness from the initial cutting parameters to the optimal cutting parameters is about 50% suggesting that the Taguchi parameter design is an efficient and effective method for optimizing surface roughness in a hard turning operation. The exponential, first order linear and second order prediction models were obtained using multiple regression. The results obtained by means of prediction models prove that they can be used to predict surface roughness in hard turning, within the experimental domain, with a reasonable degree of approximation.

Farhad Kolahan *et al.* (2011) the main objective of this study is to simultaneously model and optimize machining parameters and tool geometry in order to improve the surface roughness for AISI1045 steel. A Taguchi approach is employed to gather experimental data. Then, based on S/N ratio, the best sets of cutting parameters and tool geometry specifications have been determined. Using these parameters values, the surface roughness of AISI1045 steel parts is minimized. A medium duty lathe with 2 kw spindle power was used to perform experiments. The tool employed in experiments was HSS (5% Cobalt). This was selected since the tool angles can be implemented simply in this kind of cutting tools. The average surface roughness (Ra) in the direction of the tool movement was measured in three different places of the machined surface using a surface roughness tester, Taylor-Hobson. Several levels of machining parameters and tool geometry specifications are considered as input parameters. The surface roughness is selected as process output measure of performance. The important controlling process parameters and tool geometry in turning include rake angle ¥, side cutting edge angle X, end cutting edge angle X', cutting speed v and feed rate f as shown in Figure 22. In turn depth of cut, nose radius and free angle are set as constant parameters.

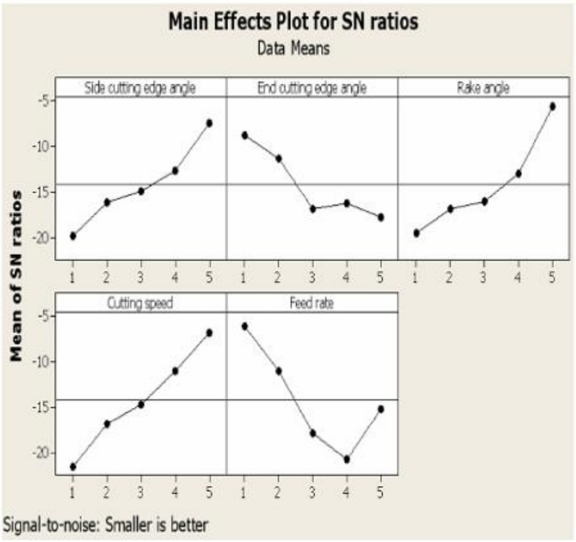
Figure 22: Turning of AISI1045 Steel



Source: Farhad Kolahan et al. (2011)

Figure 23 represents the mean S/N ratio for the side cutting edge angle, end cutting edge angle, rake angle, feed rate and cutting speed, respectively. The values of the graphs indicate that, based on S/N ratio, the optimal machining and tool geometry parameters for surface roughness are x5, x'1, ¥5, v5 and f1. The results illustrates that feed rate has slightly more effect on the surface roughness than the cutting speed.

Figure 23: Main Effects Plot for S/N Ratio



Source: Farhad Kolahan et al. (2011)

Literature depicts that considerable amount of work has been carried out by researchers for modeling, simulation and parametric optimization of surface properties of the product in turning operation using Taguchi method. In most of the works primary parameters speed, feed, and depth of cut were considered for optimization. The acceptability of the work can be increased with the inclusion of more number of process and performance parameters in the experimentation.

SUMMARY

Optimizing machining parameters for different processes is intended to improve the machining efficiencies by reducing the cost and time involved in manufacturing processes as per today's economic need. Reducing quality loss by designing the products and processes to be insensitive to variations in noise variables is a novel concept to statisticians and quality engineers. Taguchi method for experimental design is straightforward and easy to apply to many engineering situations, making it a powerful yet simple tool. It can be used to identify problems in a manufacturing process from data already in existence. It helps in the identification of key parameters that have the most effect on the performance characteristic value so that further experimentation on these parameters can be performed and the parameters that have little effect can be ignored. Orthogonal Array in Taguchi technique will help to finalize the number of levels, thus finalize the number of experiments and Signal to Noise ratio will help us to observe the behavior of quality characteristics of work piece. Taguchi approach has a potential for savings in experimental time and cost on product or process, development and quality improvement as it requires minimum number of experiments. There is general agreement that offline experiments during the product or process design stage are of great value and the methodology is based on solid engineering principles. Taguchi Method uses the idea of fundamental functionality, which will facilitate people to identify the common goal because it will not change from case to case and can provide a robust standard for widely and frequently changing situations. It is also pointed out that the Taguchi method is also very compatible with the human focused quality evaluation approaches that are coming up.

ACKNOWLEDGMENT

The authors wish to acknowledge support for this work from Dr. T. D. John, The Principal, Dr. K. M. Peethambaran, HOD (Mechanical), Faculty and Staff of Mechanical Engineering Department, Government College of Engineering, Kannur, Kerala.

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