DESIGN OPTIMIZATION OF CUTTING PARAMETERS FOR TURNING OPERATION BASED ON TAGUCHI METHOD

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Dedicated to my beloved

‘Father and Mother’

For their endless support in term of motivation,

Supportive and caring as well throughout the whole project

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ABSTRACT

Modern manufacturers, seeking to remain competitive in the market, rely on their manufacturing engineers and production personnel to quickly and effectively set up manufacturing processes for new products. Taguchi Parameter Design is a powerful and efficient method for optimizing quality and performance output of manufacturing processes, thus a powerful tool for meeting this challenge. This thesis discusses an investigation into the use of Taguchi Parameter Design for optimizing surface roughness generated by a conventional lathe. Control parameters being consider in this thesis are spindle speed, feed rate and depth of cut. After experimentally turning sample workpieces using the selected orthogonal array and parameters, this study expected to produce an optimum combination of controlled parameter for the surface roughness.

ABSTRAK

Pembuatan zaman moden, mencari faktor untuk terus bersaing di pasaran, perlu bergantung kepada jurutera pembuatan dan operater pengeluar untuk bekerja dengan cepat dan effektif dalam menyediakan proses pembuatan untuk produk baru. Kaedah parameter Taguchi adalah suatu kaedah yang berguna dan berkesan untuk mengoptimunkan kualiti dan kesan penghasilan , oleh itu, ia merupakan suatu kaedah yang berguna untuk mengatasi cabaran ini.Tesis ini membincangkankan suatu kajian dalam menggunakan kaedah parameter Taguchi untuk mengoptimunkan kekasaran permukaan yang di hasilkan oleh mesin larik. Parameter yang di pilih dalam tesis ini ialah kelajuan spindle, kadar potongan dan kedalaman potongan.Selepas selesai melarik bahan kerja bedasarkan susunan ortogonal dan parameter, kajian ini di jangka dapat menghasilkan satu kombinasi parameter yang optimum untuk kekasaran permukaan.

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CHAPTER 1

INTRODUCTION

1.1 PROJECT OVERVIEW

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.

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.

1.2 PROJECT OBJECTIVE

1. Demonstrate a systematic procedure of using Taguchi parameter design in process control of turning machines.
2. Determine optimum turning parameter for surface roughness

1.3 PROJECT SCOPE

1. Study is used the application of Taguchi method to optimize the cutting parameter for turning operation.
2. 2-inch diameter aluminum alloy rod will be machining using conventional lathe machine
3. STATISTICA software use in analyze the collected result
4. Material and hardware that will be used are all available at mechanical lab.

1.4 PROBLEM STATEMENT

Optimization of turning parameters is usually a difficult work where the following aspects are require such as like knowledge of machining and the specification of machine tool capabilities.

The level of parameters is the main point because it will affect the surface of the work piece, it also to avoid from scratch marks or inaccuracies in the cut. In a turning operation, it is important task to select a good combination of parameters level for achieving high cutting performance. Generally, this combination is hard to find.

1.5 IMPORTANT OF STUDY

As a future engineer, know how to establish a machining optimization turning parameter with high quality material that will be produced in order to increase the profit is vital.

By understanding the concepts, develop and implement the suitable optimization technique for a wide variety of problem in the area of design and manufacturing can be done.

This project also will increase the knowledge about the way to optimize the machining parameter in order to obtain the minimum surface roughness. These optimization technique parameters is also prevent engineer or production controller from doing something that waste in production such as time and produce a better product.

1.6 SUMMARY

This chapter discussed about the project background such as the important of this manufacturing optimization. It is also described the problem statement of this project, the important to the study, the objective and the scope of the project (limitation of the project).

CHAPTER 2

LITERATURE REVIEW

2.1. INTODUCTION

This chapter discussed about the turning process turning parameter and the previous study that involved the optimization technique. Here, the optimization technique, Taguchi method is review to get fully understanding before applied to the study.

2.2 TURNING PROCESS

Turning is a form of machining, a material removal process, which is used to create rotational parts by cutting away unwanted material as shown in Figure 2.1. The turning process requires a turning machine or lathe, work piece, fixture, and cutting tool.

The work piece is a piece of pre-shaped material that is secured to the fixture, which itself is attached to the turning machine, and allowed to rotate at high speeds. The cutter is typically a single-point cutting tool that is also secured in the machine. The cutting tool feeds into the rotating work piece and cuts away material in the form of small chips to create the desire shape.[12]

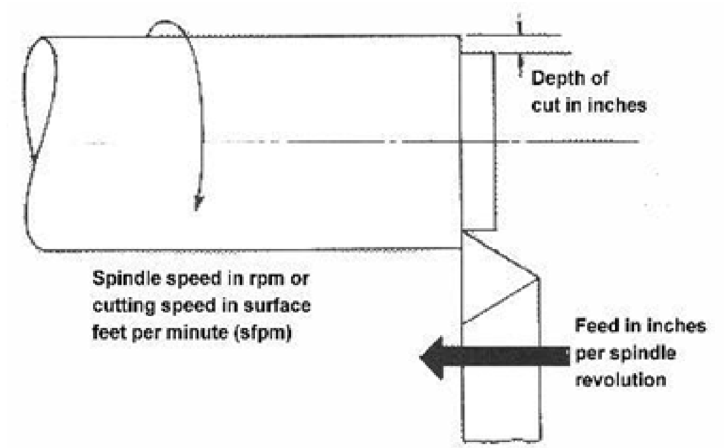


Figure 2.1 Turning process

2.3 TURNING MACHINE

Turning machines typically referred to as lathes, can be found in a variety of sizes and designs. While most lathes are horizontal turning machines, vertical machines are sometimes used, typically for large diameter work pieces. Turning machines can also be classified by the type of control that is offered.

A manual lathe requires the operator to control the motion of the cutting tool during the turning operation. Turning machines are also able to be computer controlled, in which case they are referred to as a computer numerical control (CNC)

lathe. CNC lathes rotate the work piece and move the cutting tool based on commands that are preprogrammed and offer very high precision. In this variety of turning machines, the main components that enable the work piece to be rotated and

the cutting tool to be fed into the work piece remain the same. Figure 2.2 show the lathe machine and it components.[12]

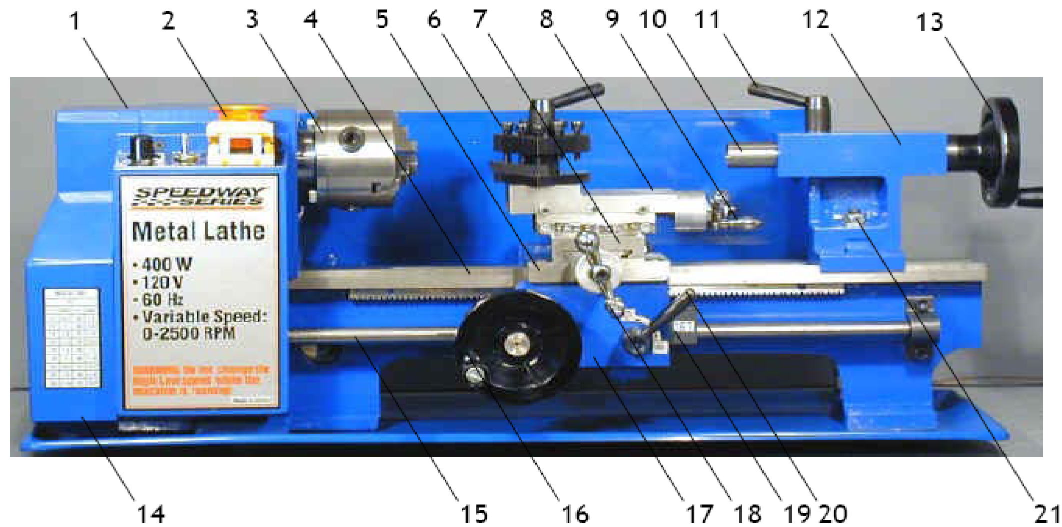


Figure 2.2 Lathe Machine

1. Headstock
2. Motor controls
3. 3-jaw chuck
4. Bed ways
5. Carriage
6. Tool post
7. Cross slide
8. Compound rest
9. Compound rest feed handle
10. Tailstock quill
11. Tailstock quill locking lever
12. Tailstock
13. Tailstock quill hand wheel
14. Change gear cover
15. Lead screw
16. Carriage hand wheel
17. Apron
18. Cross slide feed handle
19. Threading dial
20. Power feed lever
21. Tailstock lock

2.4 Turning Cutting Tool

All cutting tools that are used in turning can be found in a variety of materials, which will determine the tool's properties and the work piece materials for which it is best suited. These properties include the tool's hardness, toughness, and resistance to wear. The most common tool materials that are used include the following:[12]

- High-speed steel (HSS)
- Carbide
- Carbon steel
- Cobalt high speed steel

The material of the tool is chosen based upon a number of factors, including the material of the work piece, cost, and tool life. Tool life is an important characteristic that is considered when selecting a tool, as it greatly affects the manufacturing costs. A short tool life will not only require additional tools to be purchased, but will also require time to change the tool each time it becomes too worn.

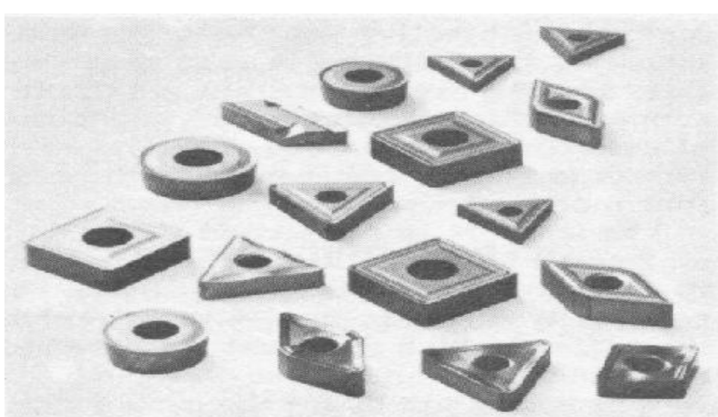


Figure 2.3 Shapes of turning cutting tool

2.4.1 Carbide Cutting Tool (Tungsten-carbide Cobalt)

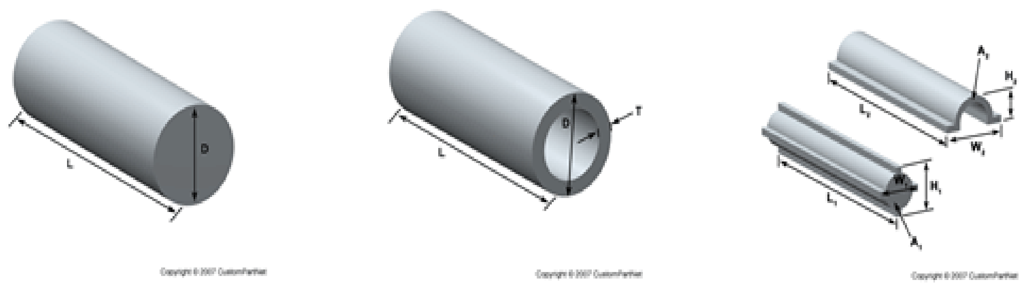
Carbide cutting surfaces are often useful when machining through materials such as carbon steel or stainless steel, as well as in situations where other tools would wear away, such as high-quantity production runs. Sometimes, carbide will leave a better finish on the part, and allow faster machining. Carbide tools can also withstand higher temperatures than standard high speed steel tools. The material is usually tungsten-carbide cobalt, also called "cemented carbide", a metal matrix composite where tungsten carbide particles are the aggregate and metallic cobalt serves as the matrix. The process of combining tungsten carbide with cobalt is referred to as sintering or Hot Isostatic Pressing (HIP).

2.5. TURNING MATERIAL

In turning, the raw form of the material is a piece of stock from which the work pieces are cut. This stock is available in a variety of shapes such as solid cylindrical bars and hollow tubes. Custom extrusions or existing parts such as castings or forgings are also sometimes used. Turning can be performed on a variety of materials, including most metals and plastics. Figures 2.3 show the shape of turning material.

Common materials that are used in turning include aluminum, brass, magnesium, nickel, steel, thermoplastics, titanium and zinc. When selecting a material, several factors must be considered, including the cost, strength, resistance to wear, and machinability. The machinability of a material is difficult to quantify, but can be said to posses the following characteristics:[12]

- Results in a good surface finish
- Promotes long tool life
- Requires low force and power to turn
- Provides easy collection of chips



Round bar **Round tube** **Custom extrusions**

Figure 2.3 Shapes of turning material

2.5.1 Aluminum Alloy

Aluminum is a soft, lightweight, malleable metal with appearance ranging from silvery to dull gray, depending on the surface roughness. The yield strength of pure aluminum is 7–11 MPa, while aluminum alloys have yield strengths ranging from 200 MPa to 600 MPa.

Aluminum has about one-third the density and stiffness of steel. It is ductile, and easily machined, cast, and extruded. Aluminum is one of the few metals that retain full silvery reflectance in finely powdered form, making it an important component of silver paints. Aluminum is a good thermal and electrical conductor, by weight better than copper. Aluminum is capable of being a superconductor, with a superconducting critical temperature of 1.2 Kelvin and a critical magnetic field of about 100 gauss

2.6. TURNING PARAMETER

In turning, the speed and motion of the cutting tool is specified through several parameters. These parameters are selected for each operation based upon the workpiece material, tool material, tool size, and more. Turning parameter that can affect the process are:[12]

- Cutting speed - The speed of the work piece surface relative to the edge of the cutting tool during a cut, measured in surface feet per minute (SFM).
- Spindle speed - The rotational speed of the spindle and the work piece in revolutions per minute (RPM). The spindle speed is equal to the cutting speed divided by the circumference of the work piece where the cut is being made. In order to maintain a constant cutting speed, the spindle speed must vary based on the diameter of the cut. If the spindle speed is held constant, then the cutting speed will vary.
- Feed rate - The speed of the cutting tool's movement relative to the work piece as the tool makes a cut. The feed rate is measured in millimeter per revolution (RPM)
- Axial depth of cut - The depth of the tool along the axis of the work piece as it makes a cut, as in a facing operation.
- Radial depth of cut - The depth of the tool along the radius of the work piece as it makes a cut, as in a turning or boring operation. A large radial depth of cut will require a low feed rate, or else it will result in a high load on the tool and reduce the tool life. Therefore, a feature is often machined in several steps as the tool moves over at the radial depth of cut.

2.7. PREVIOUS STUDY

Many studies have been made using Taguchi Method to optimize the turning parameter. M. Nalbalt et al (2006) use L9 orthogonal array with nine total experiment, 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 considerations of surface roughness. The experimental results demonstrate that the insert radius and feed rate are the main parameters among the three controllable factors (insert radius, feed rate and depth of cut) that influence the surface roughness in turning AISI 1030 carbon steel.

W.H Yang and Y.S Tang (1997) carried out an experiment consist of eighteen combination 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. Result show that cutting speed and feed rate are the significant cutting parameters for affecting tool life, while the change of the depth of cut in the range has an insignificant effect on tool life. 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%.

E.D Kirby et al (2005) use the application of the Taguchi parameter design method to optimizing the surface finish in a turning operation. This study was conducted using samples cut from a single length of 1-in diameter 6061-T6 aluminum alloy rod. The control parameters for this operation included: spindle speed, feed rate, depth of cut, and tool nose radius. Noise factors included are varying room temperature, as well as the use of more than one insert of the same specification, which introduced tool dimension variability. A total of 36 experimental runs were conducted using an orthogonal array. The study found that the control factors had varying effects on the response variable, with feed rate and tool nose radius having the highest effects. The noise factors, on the other hand, were found to not have a statistically noticeable effect.

Many others optimization studies using turning parameter as their case are described in the Table 2.1.

Table 2.1 Summary on some optimization technique.

Researcher (s)	Year	Description
K. Vijakumar, G.Prabhaharan, P. Asokan, R. Saravanan	2003	Proposes a new optimization technique based on the ant colony algorithm for solving multi-pass turning optimization problems. The machining parameters are determined by minimizing the unit production cost, subject to various practical machining constraints. The results of the proposed approach are compared with results of simulated annealing and genetic algorithm. The ACO algorithm can obtain a near-optimal solution in an extremely large solution space within a reasonable computation time.
Yusuf Sahin, A. Riza Motorcu	2004	Response surface methodology is used to develop surface roughness model for turning of mild steel with coated carbide tools. Parameters under study are cutting speed, feed rate and depth of cut. Result show that feed rate has the most significant effect, followed by cutting speed and lastly depth of cut.
Ramo´n Quiza Sardin˜as_,Marcelino	2005	This paper presents a multi-objective optimization technique, based on genetic algorithms, to optimize the cutting parameters in turning processes: cutting depth, feed and speed.

Rivas Santana, Eleno Alfonso Brindis		Two conflicting objectives, tool life and operation time, are simultaneously optimized.
Chang-Xue (Jack) Feng Xianfeng Wang	2002	This research focuses on developing an empirical model for prediction of surface roughness in finish turning. The model considers the following working parameters: workpiece hardness (material), feed, cutting tool point angle, depth of cut, spindle speed, and cutting time.. The result show that the feed, point angle, depth of cut, spindle speed and cutting time significantly affect the surface roughness.
Franci Cus Uros Zuperl	2006	A multiple-objective turning optimization problem with limitation non-equations and with three conflicting objectives (production rate, operation cost, and quality of machining) are being consider using artificial neural network approach. The parameters selected are cutting speed, feed rate and depth of cut.

2.8 TAGUCHI METHOD

Genichi Taguchi, a Japanese engineer and statisticians is the developer of the Taguchi Method. He proposed that engineering optimization of a process or product should be carried out in a three-step approach: system design, parameter design, and tolerance design. [7]

In system design, the engineer applies scientific and engineering knowledge to produce a basic functional prototype design, this design including the product design stage and the process design stage. In the product design stage, the selection of materials, components, tentative product parameter values, etc., are involved. As to the process design stage, the analysis of processing sequences, the selections of production equipment, tentative process parameter values, etc., are involved. Since system design is an initial functional design, it may be far from optimum in terms of quality and cost.

Following on from the system design is parameter design. The objective of the parameter design is to optimize the settings of the process parameter values for improving performance characteristics and to identify the product parameter values under the optimal process parameter values. In addition, it is expected that the optimal process parameter values obtained from the parameter design are insensitive to the variation of environmental conditions and other noise factors. Therefore, the parameter design is the key step in the Taguchi method to achieving high quality without increasing cost. [7]

Finally, tolerance design is used to determine and analyze tolerances around the optimal settings recommend by the parameter design. Tolerance design is required if the reduced variation obtained by the parameter design does not meet the required performance, and involves tightening tolerances on the product parameters or process parameters for which variations result in a large negative influence on the required product performance. Typically, tightening tolerances means purchasing better- grade materials, components, or machinery, which increases cost. [9]

2.8.1. Taguchi Method for Parameter Design

Taguchi Method treat optimization parameter problem into two categories, static and dynamic problem. For this study, static problem is the subject for considerations. Generally, a process to be optimized has several control factors which directly decide the target or desired value of the output. The optimization then involves determining the best control factor levels so that the output is at the target value. Such a problem is called as a "STATIC PROBLEM".

This is best explained using a P-Diagram which is shown below(Figure 2.5) ("P" stands for Process or Product). Noise is shown to be present in the process but should have no effect on the output. This is the primary aim of the Taguchi experiments - to minimize variations in output even though noise is present in the process. The process is then said to have become ROBUST.[13]

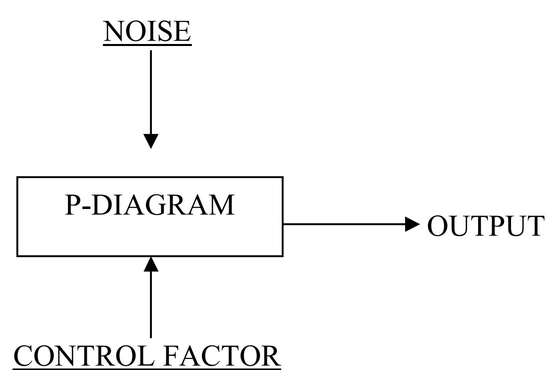


Figure 2.5 P- Diagram

There are 3 Signal-to-Noise ratios of common interest for optimization of Static Problems;[13]

(I) SMALLER-THE-BETTER:

$n = -10 \, Log_{10}$ [mean of sum of squares of measured data] (Eq. 2.1)

This is usually the chosen S/N ratio for all undesirable characteristics like “defects “etc. for which the ideal value is zero. Also, when an ideal value is finite and its maximum or minimum value is defined (like maximum purity is 100% or minimum time for making a telephone connection is 1 sec) then the difference between measured data and ideal value is expected to be as small as possible. The generic form of S/N ratio then becomes,

$n = -10 \, Log_{10}$ [mean of sum of squares of {measured - ideal}] (Eq. 2.2)

(II) LARGER-THE-BETTER:

$n = -10 \, Log_{10}$ [mean of sum squares of reciprocal of measured data]

This case has been converted to SMALLER-THE-BETTER by taking the reciprocals of measured data and then taking the S/N ratio as in the smaller-the-better case.

(III) NOMINAL-THE-BEST:

$$n = 10 \, Log_{10} \frac{\text{Square of mean}}{\text{variance}} \qquad \text{(Eq. 2.3)}$$

This case arises when a specified value is MOST desired, meaning that neither a smaller nor a larger value is desirable.

Examples are;

(i) Most parts in mechanical fittings have dimensions which are nominal-the-best type.

(ii) Ratios of chemicals or mixtures are nominally the best type.

2.8.2 Steps in Taguchi Method

The general steps involved in the Taguchi Method can be described as follows [13]

1. Define the process objective, or more specifically, a target value for a performance measure of the process. This may be a flow rate, temperature, etc. The target of a process may also be a minimum or maximum; for example, the goal may be to maximize the output flow rate. The deviation in the performance characteristic from the target value is used to define the loss function for the process.

2. 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 for the parameters should be varied and must be specified. For example, a temperature might be varied to a low and high value of 40 C and 80 C. increasing the number of levels to vary a parameter at increases the number of experiments to be conducted.

3. Create orthogonal arrays for the parameter design indicating the number of and conditions for each experiment.

4. Conduct the experiments indicated in the completed array to collect data on the effect on the performance measure.

5. Complete data analysis to determine the effect of the different parameters on the performance measure. These data analysis include the S/N ratio analysis, ANOVA analysis and conformation experiment.

2.8.3. Advantages of Taguchi Method

An advantage of the Taguchi method is that it emphasizes a mean performance characteristic value close to the target value rather than a value within certain specification limits, thus improving the product quality. Additionally, Taguchi's method for experimental design is straightforward and easy to apply to many engineering situations, making it a powerful yet simple tool.[13]

It can be used to quickly narrow down the scope of a research project or to identify problems in a manufacturing process from data already in existence. Also, the Taguchi method allows for the analysis of many different parameters without a prohibitively high amount of experimentation. In this way, it allows for 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. Table 2.2 have list out the comparison between Taguchi Method and the traditional design of experiment.[8]

Table 2.2 Comparison between Taguchi Method and traditional design of experiment (DOE)

Aspect	DOE method	Taguchi method
Process knowledge	Assumes no fundamental understanding of the process being investigated	Requires knowledge of the process and the interactions likely to exist between inputs
Number of tests	Requires all combinations of inputs	Requires a much smaller number of combinations
Noise factors	Traditionally ignores noise factors, but they can be added	Includes the noise factors in the design
Variability	Ignores variability and assumes a deterministic nature of the system to find the most effective combinations of inputs to maximize or minimize output	Assumes a stochastic system, looking at both levels and variability of the output to allow the selection of input variable combinations to optimize output or minimize variability
Confirming experiment	Does not require a confirming experiment, since all input combinations were tested	Should include a confirming experiment

2.9. STATISTICA SOFTWARE

STATISTICA software is the software use in selection of procedures to design and analyze the experimental designs used in industrial (quality) research. For Taguchi Method, STATISTICA Design of Experiments can generate orthogonal arrays for up to 31 factors; designs with up to 65 factors can be analyzed. As in all other types of designs, the runs of the experiment can be randomized, and the user can add blank columns to the Spreadsheet to generate convenient data entry forms.

The user can also examine the aliases of two-way interactions. *STATISTICA Design of Experiments* will automatically compute the standard signal-to-noise (*S/N*) ratios for problems of these types: Smaller-the-better, Nominal-the-best, and Larger-the-better. In addition, untransformed data can also be analyzed; thus, the user can produce any type of customized *S/N* ratios via *STATISTICA* Visual Basic and analyze them with this procedure. In addition to comprehensive descriptive statistics, the user can review the computed *S/N* ratios. The full ANOVA results are displayed in an interactive Spreadsheet in which the user can "toggle" effects into or out of the error term.

A similar interactive Spreadsheet allows the user to predict *Eta* (the *S/N* ratio) under optimum conditions, that is, settings of levels of factors. Again, the user can "toggle" effects into or out of the model, and specify particular levels for factors. Finally, the means can be summarized in a standard main effect plot of *Eta* by factor level; if an accumulation analysis on categorical data is performed, the results can be summarized in a stacked bar plot as well as line plots of the cumulative probabilities across categories for the levels of selected factors.

CHAPTER 3

METHODOLOGY

3.1 PROJECT FLOW CHART

For this project, it starts with gathering information about all the important data that are going to use in this study. This are included the previous study about the optimization technique for turning, turning process and it machining condition. Then the Taguchi Method which is going to apply is explored and the STATISTICA software is used to help in analyzing the result.

After fully understand the concept of Taguchi Method, only then, the turning parameter which will be optimized and the response variable can be determined. Experiment then will be run and the surface roughness values will be measured. After all the results are obtained, data analysis is carry out using the STATISTICA software.

Next the conformation experiment need to run to justify the optimized parameter obtain from the data analysis. Final step is to complete the report and preparation for presentation. Complete report consists of introduction, literature review, methodology, result and discussion and conclusion and recommendation then will submit for marking.

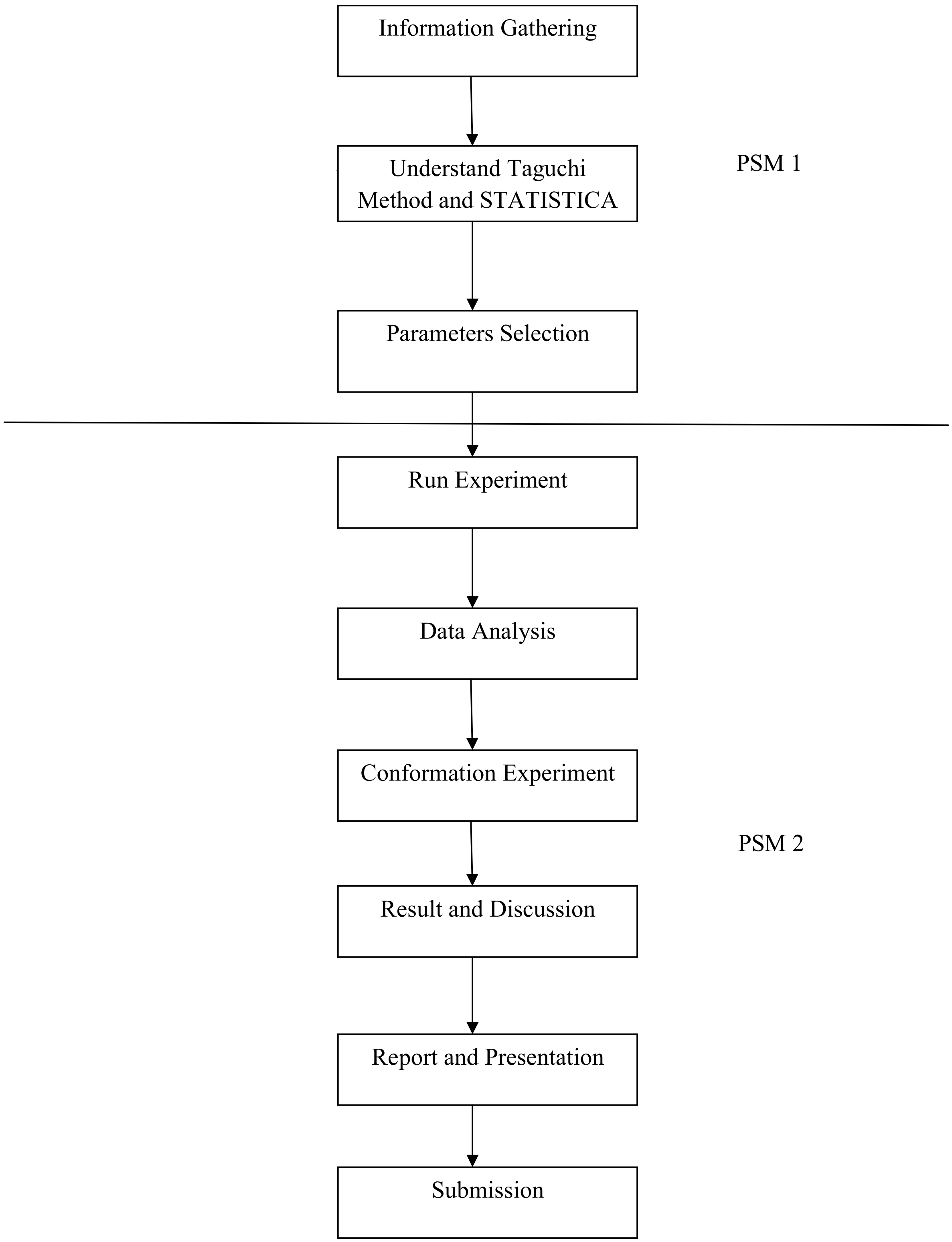


Figure 3.1 Project flow chart

3.2 STEP IN TAGUCHI METHOD

Overall, there are five general steps in applying Taguchi Method. These step are shown as in the Figure 3.2

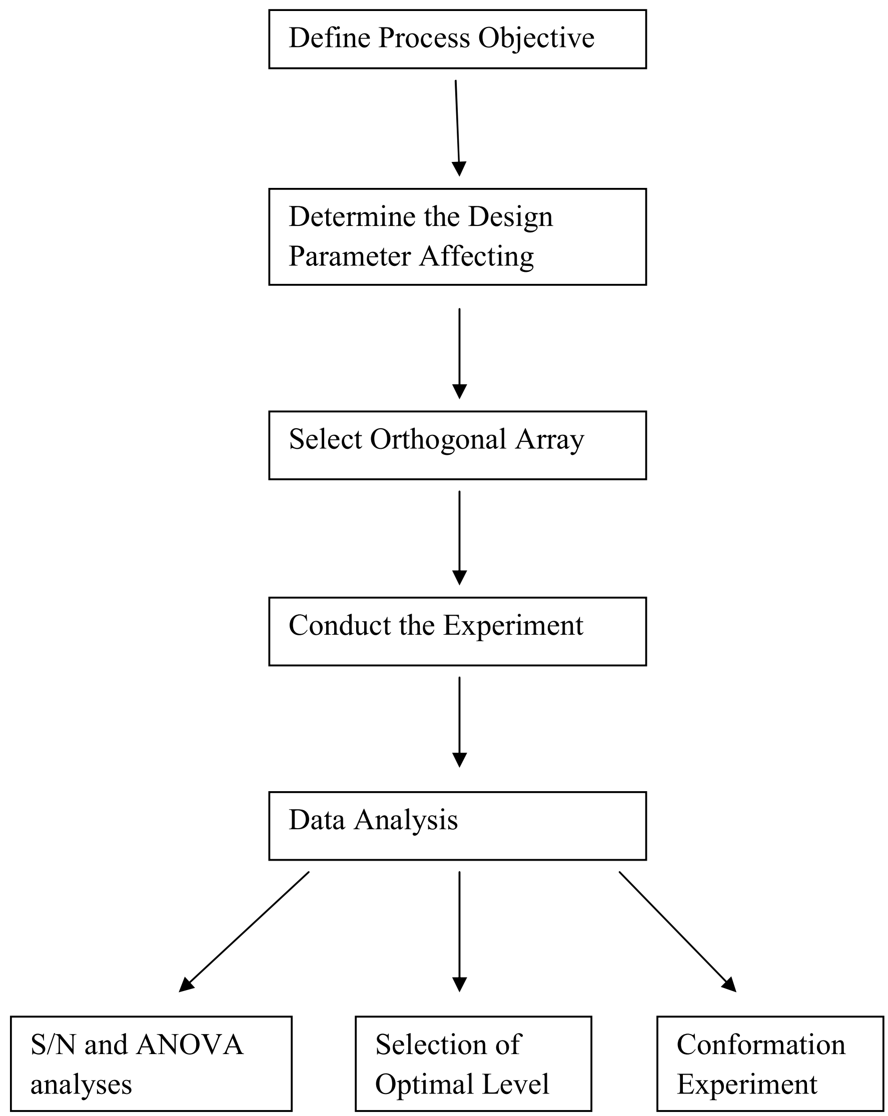


Figure 3.2 Steps in Taguchi Method

3.3 DEFINE THE PROCESS OBJECTIVE

The process objective or more specifically, a target value as a performance measure of the process. The goal of this study is to produce minimum surface roughness (Ra) in a turning operation. Smaller Ra values represent better or improved surface roughness. Therefore, a smaller-the-better quality characteristic will be implemented and introduced in this study.

3.4 DETERMINE PARAMETER AFFECTING THE PROCESS

Several studies exists which explore the effect of feed rate, spindle speed, and depth of cut on surface finish. These studies all supported the idea that feed rate has a strong influence on surface finish. Spindle speed and depth of cut were found to have differing levels of effect in each study, often playing a stronger role as part of an interaction. This would seem to indicate that these controlled parameters would play an important role in optimizing surface roughness.

The parameters in this experiment have three level, spindle speed at 1305, 1600 and 2570 RPM. Feed rate at 0.10, 0.18 and 0.28 mm/rev and depth of cut at the 0.6, 1.1 and 1.6 mm. These ranges of feed rate would be expected to produce a good finish on the parts, and the spindle speed and depth of cut were selected to meet the hardware setup specifications while providing reasonable variability in the experiment. It was also intended that this would allow the selection of an orthogonal array with as few runs as possible, while still allowing for a robust experiment.

Table 3.1 Cutting parameter and their level

Symbol	Cutting Parameter	Level 1	Level 2	Level 3
A	Spindle speed (RPM)	1305	1600	2750
B	Feed rate (mm/rev)	0.10	0.18	0.28
C	Depth of cut (mm)	0.6	1.1	1.6

3.5 SELECT ORTHOGONAL ARRAY

Once the parameters affecting a process that can be controlled and the levels at which these parameters should be varied has been determined, next step is to select the appropriate orthogonal array. For this study, three parameters are selected with three levels.

Based on the array selector in the Table 3.2, L9 orthogonal array will be selected. This array contains four columns and nine rows and has eight degrees of freedom. Each cutting parameter is assigned to a column, nine cutting-parameter combinations being available.

Therefore, only nine experiments are required to study the entire parameter space using the L9 orthogonal array. The experimental layout for the three cutting parameters using the L9 orthogonal array is shown in Table 3.3. Since the L9 orthogonal array has four columns, one column of the array is left empty for the error of experiments: orthogonality is not lost by letting one column of the array remain empty.

Table 3.2 Array Selector

Number of Levels	Number of Parameters (P)																					
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
2	L4	L4	L8	L8	L8	L8	L12	L12	L12	L12	L16	L16	L16	L16	L32	L32	L32	L32	L32	L32	L32	L32
3	L9	L9	L9	L18	L18	L18	L18	L27	L27	L27	L27	L27	L36	L36	L36	L36	L36	L36	L36	L36	L36	L36
4	L'16	L'16	L'16	L'16	L'32	L'32	L'32	L'32	L'32													
5	L25	L25	L25	L25	L25	L50	L50	L50	L50	L50	L50											

Table 3.3 Experiment layout using L9 orthogonal array

Experiment number	Cutting parameter level		
	Cutting speed [A]	Feed rate[B]	Depth of cut [C]
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	3
5	2	2	1
6	2	3	2
7	3	1	2
8	3	2	3
9	3	3	1

3.6 CONDUCT THE EXPERIMENT

The experiments will be conducted as indicated in the completed L9 orthogonal array to collect data on the effect on the performance measure. In this study the performance that we want to measure is surface roughness. Experiment will be carried out based on the data in Table 3.4

Table 3.4 Experiment number and their parameter combination

Number of Experiment	Cutting Parameter level			Surface Roughness (micrometer)
	Cutting speed (m/min)	Feed Rate(mm/rev)	Depth of Cut(mm)	
1	1305	0.10	0.6	
2	1305	0.18	1.1	
3	1305	0.28	1.6	
4	1600	0.10	1.1	
5	1600	0.18	1.6	
6	1600	0.28	0.6	
7	2570	0.10	1.6	
8	2570	0.18	0.6	
9	2570	0.28	1.1	

3.6.1 Preparing the lathe for operation

1. Clean and lubricate the lathe. Use the lubricants specified by the manufacturer.
2. Turn the spindle by hand to make sure it is not locked in back gear. Set the drive mechanism to the desired speed and feed.
4. Move the carriage along the ways; there should be no binding.
5. Inspect the cross-feed and compound rest slides. Adjust the gibs if there is too much play. Do not permit excessive overhang of the compound rest.
6. Inspect the tailstock if it is to be used for any portion of the operation. Check it for alignment and use a smooth dead center.
7. Place the proper work holding attachment on the headstock spindle. Clean the threads and apply a drop of oil.
8. Sharpen the cutter bit. Clamp it in the appropriate tool holder.

3.6.2 Measuring Surface Roughness

For measuring the surface roughness, Mahr Perthometer will be used. The procedure are as follow:

1) Switch on the Perthometer machine by pressing START button for approximately 1 second.

2) Place a sample on the platform.

3) Select the view "Measuring Station" by pressing M button.

4) Position the pick-up (stylus) approximately in the centre.

5) Start measurement by pressing START button.

6) For each sample, repeat the measurement three times so that averages could be calculated in order to minimize the variability.

3.7 DATA ANALYSIS

Data analysis are included the S/N ratio analysis, ANOVA analysis, selection of the optimal levels of design parameters, and verification of the optimal design parameters through the confirmation experiment.

3.7.1 S/N Ratio Analysis

In the Taguchi method, the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value (S.D.) for the output characteristic. Therefore, the S/N ratio is the ratio of the mean to the S.D. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. The S/N ratio, ή is defined as:

$$\acute{\eta} = -10 \log (M.S.D.) \qquad \text{(Eq.3.1)}$$

where M.S.D is the mean square deviation for the output characteristic.

There are three categories of quality characteristics, i.e. the-lower-the-better, the higher-the-better, and the-nominal-the-better. To obtain optimal cutting performance, the-lower-the-better quality characteristics for surface roughness should be taken. The M.S.D. for the the-lower-the-better quality characteristic can be expressed as:

$$M.S.D. = 1/M \sum_{i=1}^{m} Si^2 \qquad \text{(Eq.3.2)}$$

Where *Si* is the value of surface roughness for the *i* th test.

3.7.2 ANOVA Analysis

The purpose of the analysis of variance (ANOVA) is to investigate which design parameters significantly affect the quality characteristic. This is to accomplished by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean S/N ratio, into contributions by each of the design parameters and the error.

The ANOVA analysis will be analyzed using the STATISTICA software. To determine whether the parameters have the significant effect or not, E. D. Kirby (2006) use the F-ratios calculated in the ANOVA for each parameter to determine this, with the following criteria:

♦ $F < 1$: Control factor effect is insignificant (experimental error outweighs the control factor effect).

♦ $F \approx 2$: Control factor has only a moderate effect compared with experimental error.

♦ $F > 4$: Control factor has a strong (clearly significant) effect.

3.7.3 Confirmation Experiment.

Once the optimal level of the design parameters has been selected, the final step is to predict and verify the improvement of the quality characteristic using the optimal level of the design parameters. The estimated S /N ratio ή using the optimal level of the design parameters can be calculated as:

$$\acute{\eta} = \eta m + \sum_{i=1}^{o} (\eta i - \eta m) \qquad \text{(Eq.3.3)}$$

where ηm is the total mean S/N ratio, ηi is the mean S/N ratio at the optimal level, and 0 is the number of the main design parameters that affect the quality characteristic.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

In this section, the results obtained from the experiment are discussed and studied using the S/N ratio and ANOVA analyses with the help of STATISTICA software. Based on the results of the S/N and ANOVA analyses, optimal settings of the cutting parameters for surface roughness are obtained. Then, the conformation experiment is run for verification.

4.2 ANALYSIS OF THE S/N RATIO

In the Taguchi method, the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value (S.D.) for the output characteristic. Therefore, the S/N ratio is the ratio of the mean to the S.D.

Taguchi uses the S/N ratio to measure the quality characteristic as mentioned earlier, there are three categories of quality characteristics, i.e. the-smaller-the-better, the higher-the-better, and the-nominal-the-best. To obtain optimal cutting performance, the-smaller-the-better quality characteristic for surface roughness must be taken. Table 4.1 show the result for the surface roughness, Ra average as measured by the surface roughness measurement device, Mahr Perthometer. From the overall nine experiments combination, experiment run number one produce the best surface roughness result and result for experiment combination number six is the worst.

Table 4.1 Surface roughness result

Number of Experiment	Cutting Parameter level			Surface Roughness (micrometer)
	Cutting speed (m/min)	Feed Rate(mm/rev)	Depth of Cut(mm)	
1	1305	0.10	0.6	0.929
2	1305	0.18	1.1	1.527
3	1305	0.28	1.6	2.993
4	1600	0.10	1.1	1.064
5	1600	0.18	1.6	1.459
6	1600	0.28	0.6	3.035
7	2570	0.10	1.6	1.089
8	2570	0.18	0.6	1.481
9	2570	0.28	1.1	3.017

S/N ratio for each combination then calculated with the help of STATISTICA software. The result for S/N ratio for each experiment is shown in the Table 4.2. Then the mean S/N ratio for each level of the cutting parameters is summarized and called the mean S/N response table for surface roughness factor as shown in Table 4.3. In addition, the totals mean S/N ratio for the nine experiments is also calculated and listed in Table 4.3. Figure 4.1 shows the mean S/N ratio graph for surface roughness.

Table 4.2 Experimental results for surface roughness and S/N ratio

Run	spindle speed(RPM)	feed rate (mm/rev)	depth of cut(mm)	Surface roughness(μm)	S/N ratio(dB)
1	1305	0.10	0.6	0.929	0.63969
2	1305	0.18	1.1	1.527	-3.67678
3	1305	0.28	1.6	2.993	-9.52214
4	1600	0.10	1.1	1.064	-0.53883
5	1600	0.18	1.6	1.459	-3.28111
6	1600	0.28	0.6	3.035	-9.64317
7	2570	0.10	1.6	1.089	-0.74056
8	2570	0.18	0.6	1.481	-3.41110
9	2570	0.28	1.1	3.017	-9.59151

The greater S/N ratio corresponds to the smaller variance of the output characteristic around the desired value (smaller-the-better). From the graph, figure 4.1 it can be concluded that the optimize cutting parameter for surface roughness is spindle speed at 1305 RPM, feed rate at 0.10 mm/rev and depth of cut at 0.6 mm. However, the relative importance amongst the cutting parameters for surface roughness still needs to be known so that optimal combinations of the cutting parameter levels can be determined more accurately. This will be discussed in the next section using the analysis of variance.

Table 4.3 Response table mean S/N ratio for surface roughness factor

Symbol	**Cutting parameter**	**Mean S/N ratio**		
		Level 1	**Level 2**	**Level 3**
A	spindle speed(RPM)	-4.18641	-4.48770	-4.58106
B	feed rate(mm/rev)	-0.21323	-3.45633	-9.58560
C	depth of cut(mm)	-4.13820	-4.60237	-4.51460

Total mean S/N ratio = -4.418 dB

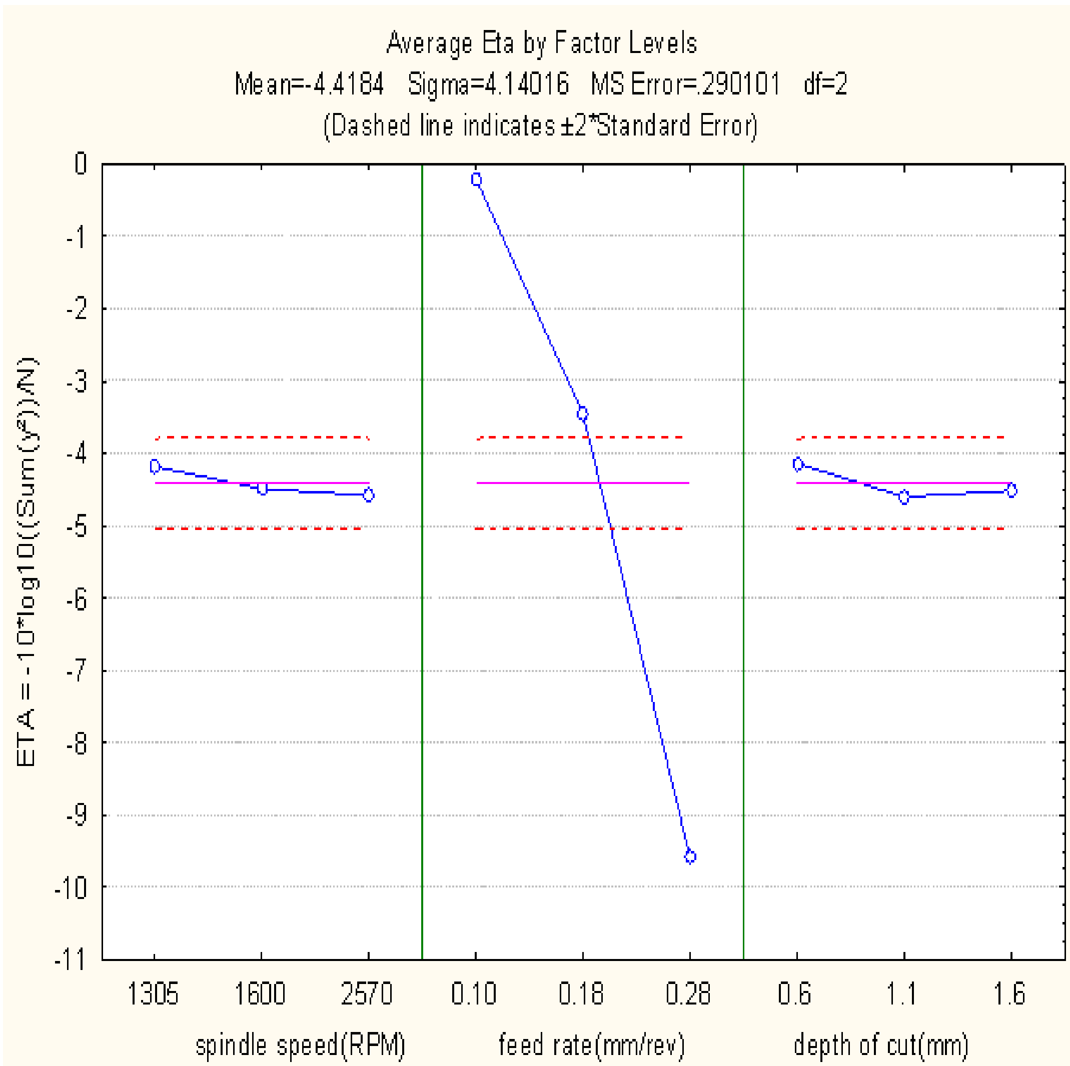


Figure 4.1. The mean of S/N ratio for each parameter at three levels

4.3 ANALYSIS OF VARIANCE

The purpose of the analysis of variance (ANOVA) is to investigate which design parameters significantly affect the quality characteristic. This can be accomplished by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean S/N ratio, into contributions by each of the design parameters and the error.

Table 4.4 shows the results of ANOVA for surface roughness. It can be found that the feed rate is the significant cutting parameters for affecting the surface roughness since the F- ratio is 234.2757 which is greater than 4. While, the change of the depth of cut, followed by spindle speed in the range given have the insignificant effect on surface roughness. Therefore, based on the S/N ratio and ANOVA analysis, the optimal cutting parameters for surface roughness are the spindle speed at level 1(1305 RPM), feed rate at level 1(0.10 mm/rev, and the depth of cut at level 1(0.6 mm).

Table 4.4. Results of the analysis of variance for surface roughness

Source of variation	**Degree of freedom**	**Sum of squares**	**Mean square**	**F- ratio**	**P value**	**Contribution (%)**
Spindle speed	2	0.2552	0.12762	0.4399	0.694487	0.186
Feed rate	2	135.9270	67.96350	234.2757	0.004250	99.125
Depth of cut	2	0.3648	0.18242	0.6288	0.613941	0.266
Error	2	0.5802	0.29010			0.423
Total	8	137.1272				100

4.4 CONFORMATION EXPERIMENT

Once the optimal level of the design parameters has been selected, the final step is to predict and verify the improvement of the quality characteristic using the optimal level of the design parameters. The prediction S /N ratio ή using the optimal level of the design parameters can be calculated as:

$$\acute{\eta} = \eta m + \sum_{i=1}^{o} (\eta i - \eta m) \qquad \text{(Eq. 4.1)}$$

where ηm is the total mean S/N ratio, ηi is the mean S/N ratio at the optimal level, and 0 is the number of the main design parameters that affect the quality characteristic.

Table 4.5 Results of the confirmation experiment for surface roughness

	Optimal cutting parameters	
	Prediction	Experiment
Level	A1B1C1	A1B1C1
Surface roughness (μm)	0.966	0.922
S/N ratio (dB)	0.2983	0.7053

Table 4.5 show the result of the prediction and conformation experiment using the optimal cutting parameters of surface roughness. The different of the prediction and the experiment using the optimal parameter for surface roughness is 4.77%, which is very small. Therefore, we can say that there is good agreement between the predicted machining performance and actual machining performance is shown.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

This study has presented an application of the parameter design of the Taguchi method in the optimization of turning operations. The following conclusions can be drawn based on the experimental results of this study:

- Taguchi's robust orthogonal array design method is suitable to analyze the surface roughness (metal cutting) problem as described in this thesis.

- 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.

- The experimental results demonstrate that the feed rate is the main parameters among the three controllable factors (spindle speed, feed rate and depth of cut) that influence the surface roughness in turning aluminum alloy rod.

- Surface roughness can be improved simultaneously through this approach instead of using engineering judgement.

- In turning, use of low spindle speed (1305 RPM), small feed rate (0.10 mm/rev) and low depth of cut (0.6 mm) are recommended to obtain better surface roughness for the specific test range.

5.2 RECOMMENDATION

Addressing issues such as numerous uncontrolled noise factors and time constraints for experimentation and implementation would be important in demonstrating Taguchi Parameter Design as a valuable and manageable tool for off-line quality engineering and production optimization in the future..

Further study could consider more factors such as cutting speed, materials, lubricant, and others in the research to see how the factors would affect surface roughness. Also, further study could consider the outcomes of Taguchi parameter design when it is implemented as a part of management decision-making processes.

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