APPLICATION OF TAGUCHI METHOD IN THE OPTIMIZATION OF CUTTING PARAMETERS FOR SURFACE ROUGHNESS IN TURNING

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ABSTRACT

In this study, the Taguchi Method is used to find the optimal cutting parameters for surface roughness in turning operation. The orthogonal array, the signal-to-noise ratio, and analysis of variance 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 considerations of surface roughness. Experimental results are provided to illustrate the effectiveness of this approach.

ABSTRAK

Dalam kajian ini, Kaedah Taguchi telah diguna pakai untuk mencari parameter pemotongan yang optimum bagi kekasaran permukaaan untuk proses putaran. Susunan orthogonal, nisbah signal-to-noise, dan variasi analisis telah digunakan untuk mengkaji pencirian prestasi dalam operasi putaran bagi batang besi AISI 1030 dengan menggunakan mata bersadur TiN. Tiga parameter pemotongan iaitu, insert radius, kadar makan, kedalaman pemotongan, telah dioptimumkan dengan mengambil kira kekasaran permukaan. Keputusan eksperimen disediakan untuk mengambarkan keberkesanan kaedah ini.

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CHAPTER 1

INTRODUCTION

1.1 Background

In competition industry, each manufacturing company wants to manufacture low cost and high quality product in a short time to full fill customer demand. Automated and flexible manufacturing systems are employed for that purpose along with computerized numerical control (CNC) machines that are capable of achieving high accuracy and very low processing time. In a turning operation, it is important task to select cutting parameter for achieving high cutting performance. Usually, the desired cutting parameters are determined based on experience or by use of handbook. Cutting parameters are reflected on surface roughness, surface texture and dimensional deviations of the product. Surface roughness, which is used to determine and to evaluate the quality of a product, is one of the major quality attributes of a turning product.

Surface roughness is a measure of the technological quality of a product and a factor that greatly influences manufacturing cost. It described the geometry of the machined surfaces and combined with the surface texture. The mechanism behind the formation of surface roughness is very complicated and process dependant. To select the cutting parameter properly, several mathematical models and based on statistical regression or neural network techniques have been constructed to establish the relationship between the cutting performance and cutting parameter. Then, an objective function with constraints is formulated to solve the optimal cutting parameter using optimization techniques. Therefore, considerable knowledge and experience are required for this approach. In this study, an alternative approach based on the Taguchi method and is used to determine the desired cutting parameter more efficiency.

1.2 Objective of the Study

1. To study and understand the Taguchi method in engineering application
2. To demonstrate use of the Taguchi parameter design in order to identify the optimum surface roughness performance with a particular combination of cutting parameter in a turning operation

1.3 Scope of the Study

In order to get the best result, this research must be scoped narrower where it consists of:

1. The Taguchi method is used to find the optimal cutting parameters for surface roughness in turning.
2. The cutting experiment was carried out on a NEF 400 Gildemeister CNC turning machine that located at Mechanical Laboratory of University Malaysia Pahang. The workpiece used for machining is AISI 1030 carbon steel bars.
3. The orthogonal array, the signal-to-noise, and analysis of variance are employed to study the performance characteristics in turning operations.
4. Using three-level array L9 as an orthogonal array as reference to setup the experiment.

1.4 Problem Statement

Turning is a widely used machining process in which a single-point cutting tool removes material from the surface of rotating cylindrical work piece. Three cutting parameters, i.e., feed rate, depth of cut, and insert radius must be determined in a turning operation. A common method of evaluating machining performance in a turning operation is based on the surface roughness. Basically, surface roughness is strongly correlated with cutting parameters such as insert radius, feed rate, and depth of cut. Proper selection of the cutting parameters based on the parameter design of the Taguchi method is adopted in this paper to improve surface roughness in a turning operation.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Taguchi method

To compete effectively in today's marketplace, companies must find ways to improve the quality of their products while lowering the cost of production. They must also bring products to the market quicker and at minimal research and development costs. Although there are many tools available for increasing productivity and solving problems, Dr Genichi Taguchi has developed a set of techniques based on statistical principles and utilizing engineering knowledge. By recognizing the importance of associating quality with the financial loss imparted by poor quality decisions based on cost effectiveness.

Dr. Genichi Taguchi methods are a product of the Japanese post – World War II era. When resources were scarce and financial support was at best minimal, the demands for reconstruction of Japanese industry were enormous. This period in Japanese history require accelerated learning and giant strides in improvement while being restrained by inferior raw material and lack of capital. From an engineering background, Dr Taguchi converted his study of statistics and advanced mathematics into a system merging statically techniques and engineering expertise (Glen Stuart, 1999).

A Taguchi philosophy stresses the importance of reducing variability; however, management is often more interested in explanations that relate to monetary units, than in part tolerances and data variability. To make this translation, Taguchi suggests using a loss function.

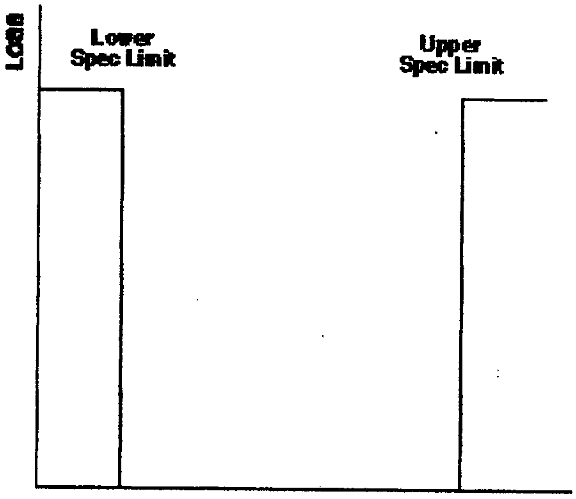

Figure 2.1 Traditional method of interpreting manufacturing limit

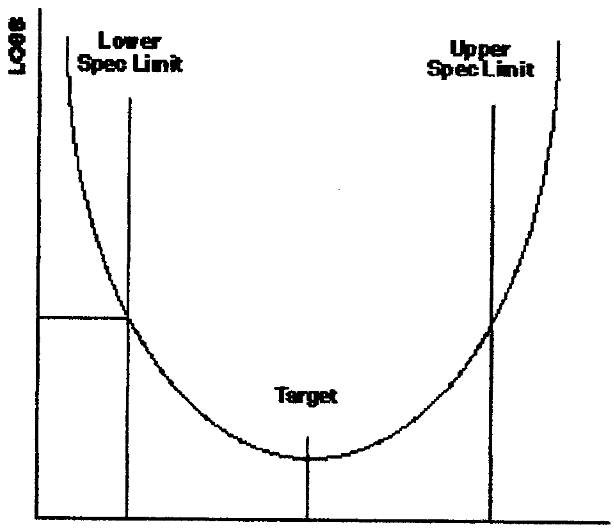

Figure 2.2 Taguchi loss function

To illustrate the Taguchi loss function, consider first Figure 2.1, which shows how component loss is typically viewed by American industries. From this figure, it seems reasonable to question the logic of considering that there is no loss if a part is at a specification limit, while another part has a loss value equal to its scrap value if it is barely outside its specification criteria. An alternative is to consider a "loss to society," as expressed in Taguchi's Loss Function. Figure 2.2 shows a quadratic loss function where scrap loss at the specification limits equates to that shown in Figure 2.1. However, with this strategy a component part has an increasing amount of loss as it deviates from its nominal specification criterion, even though it may be within its specification limits. Unlike Figure 2.1, the curve in Figure 2.2 does not have the illogical dramatic shift in loss when a part exactly meets specification versus when it is slightly beyond the specification limits.

Taguchi methods are statistical methods to improve the quality of manufactured goods and, more recently, to biotechnology, marketing and advertising. Taguchi has developed a methodology for the application of designed experiment, including a practitioner's handbook (G.Taguchi, 1988). This methodology has taken the design of experiment from the exclusive world of the statistician and brought it more fully into the world of manufacturing. His contributions have also made the practitioner work simpler by advocating the use of fewer experimental designs, and providing a clearer understanding of the variation nature and the economic consequences of quality engineering in the world of manufacturing (Glen Stuart, 1999). Taguchi introduces his approach, using experimental design for (P.J.Ross, 1988):

- Designing products/processes so as to be robust to environmental condition
- Designing and developing products/process so as to be robust to component variation.
- Minimizing variation around a target value.

Taguchi proposed that engineering optimization of a process or product should be carried out in three-step approach:

1 System design
2 Parameter design
3 Tolerances design

2.1.1 System design

The conceptual stage of any new product development or process innovation is system design. This is the "idea" stage where something revolutionary or perhaps an offshoot of previous developments is conceived and tested. The concepts may be based on their on past experience, experience, scientific/engineering knowledge, a new revelation, or any combination of three. The strategy behind system design is to take these new ideas and convert them into something that can work (Glen Stuart, 1999).

For example, we can look at the Wright Brother's airplane flown at Kitty Hawk. Their accomplishments were achieved based on their prior experience and technical know-how with engines and bicycles. Although their invention flew under a certain set of wind conditions, this did not mean that the plane could operate in diverse weather. Neither did this prove that all aircraft that they could construct with the same design would perform successfully. This only meant that the airplane could operate satisfactorily under the right conditions. In the manufacturing or design environment, this typically relates to nominal conditions or the center of specifications. Making products and process that can operate consistently well is the subject of the next design stage.

In system design there two design stage, this design including the product design stage and the process design stage (M.Nalban, 2006). In product design stage, the selection of materials, components, tentative product parameter values, etc., are involved. For process design stage, the analysis of processing sequences, the selections of production equipment, tentative process parameter values, etc., are involved.

2.1.2 Parameter design

The objective of parameter design is to take the innovation which has been proven to work in System Design and enhance it so that it will consistently function as intended. Usually by using classical parameter design there are a large number of experiment have to be carried out when the number of the process parameter increases. To solve this task, Taguchi come out with a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. Taguchi recommends the use of the loss function to measure the performance characteristics deviating from the desired value (Glen Stuart, 1999). The value of the loss function is further transformed into a signal-to-noise ratio η. There are three categories of the performance characteristics in the analysis of the S/N ratio, that is

1. The smaller- the- better
2. The nominal-the-better
3. The larger-the-better

The S/N ratio for each level of process parameters is computed based on the S/N analysis (Yuin Wu, Alan Wu, 2000). Regardless of the category of the performance characteristic, the larger S/N ration corresponds to the better performance characteristics. Therefore, the optimal level of the process parameters is the level with the highest S/N ratio η.

Furthermore, a statistical analysis of variance (ANOVA) is performed to see which process parameters are statistically significant. With the S/N and ANOVA analyses, the optimal combination of the process parameters can be predicted (Glen Stuart, 1999).

2.1.2.1 The smaller-the-better

The smaller-the-better characteristics is one in which the desired goal is to reduce the measured characteristics to zero. This applies, for instance to the porosity, vibration, fuel consumption of an automobile, tool wear, surface roughness, response time to customer complaints, noise generated from machine or engines, percent shrinkage, percent impurity in chemicals, and product deterioration.

2.1.2.2 The larger-the-better

The opposite of the lower-the-better is the larger-the-better characteristics. This is one in which the ideal value is infinity. This type characteristics applies to tensile strength, pull strength, car mileage per gallon of fuel, reliability of a device, efficiency of engines, life of components, corrosion resistance and others.

2.1.2.3 The nominal-the-better

The nominal-the-better characteristics is one where a target value is specified and the goal is minimal variability around the target. This type of characteristics is generally considered when measuring dimensions such as diameter, length, thickness, width etc. Other examples include pressure, area, volume, current, voltage, resistance, and viscosity.

2.1.3 Tolerances design

The objectives of tolerances design is to determine the acceptable range of variability around the nominal settings determined in parameter design. Again design of experiments is used to study the product or process, while analysis of variance (ANOVA) provides interpretation of the experiment data. Wide tolerance parts and cheap grade raw material whose values were determined in parameter design are used.

The strategy is to determine which tolerances and grades of material have the greatest effect on variability. Tolerances can be tightened and materials upgraded based on tradeoffs between the cost of higher grade parts or ingredients and the reduction in product/process variation.

2.2 Turning process

Turning is a widely used machining process in which a single-point cutting tool removes material from the surface of a rotating cylindrical work piece. The starting material is usually a work piece that has been made by other processes such as casting, forging, extrusion, or drawing. Three cutting parameter such as feed rate, depth of cut, and insert radius must be determined in a turning operation. Turning, being one the most common machining processes, has many applications in industry. Some typical applications include the turning of shafts, pins, drums, rollers, and disks. A few less obvious applications include the production of engine and compressor pistons, and stethoscope housings and the finishing of gears. In certain cases, using special fixtures and/or machines, non-circular objects such as high performance pistons and special rollers may be turned. Some objects, although round, may include slots or key ways which give rise to a turning condition called interrupted cutting.

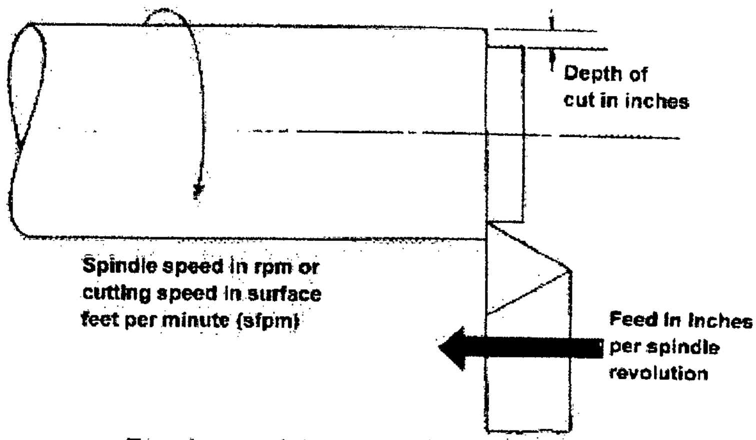

Figure 2.3 Basic operation of turning operation

2.3 Orthogonal array

The foundation for designing an experiment using Taguchi methodology is the orthogonal arrays. Although more classical types of designs, such as the full factorial and any of the wide variety of fractional, could be employed, the orthogonal array has traditionally been associated with Taguchi experimentation techniques. The orthogonal array is so efficient in obtaining only relatively small amount of data and being able to translate it into meaningful and verifiable conclusions (Glen Stuart, 1999). Furthermore, the designs of experiments utilizing orthogonal arrays are basically simple to understand and the guidelines are easy to follow.

The origin of the development of the orthogonal array is attributed to Sir R. A. Fisher of England. His early efforts in applying orthogonal arrays were to control error in an experiment (D.C Montgomery, 1997). Dr Taguchi has since adapted the orthogonal array to measure not only the effect of a factor under study on the average result, but also to determine the variation from the average result.

Orthogonal means being balanced and not mixed. In the context of experimental matrices, orthogonal means statistically independent. If we examine a typical orthogonal array (Table 2.1) we will note that each level has an equal number of occurrences within each column. For each column of the array in Table 2.1, level *1* occurs four times, and *level* 2 occurs four times as well. Although different orthogonal arrays may have more than two levels within each column and each array has a different number of columns, the same rule applies. Within each column, we will find an equal number of occurrences for each level.

Table 2.1 L_8 Orthogonal Array

$L_8(2^7)$							
No	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1
7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2

2.4 Analysis of variance

This method was developed by Sir Ronald Fisher in the 1930s as a way to interpret the results from agricultural experiments. ANOVA is not a complicated method and has a lot of mathematical beauty associated with it. ANOVA is a statistically based, objective decision-making tool for detecting any differences in average performance of groups of items tested. The decision, rather than using pure judgment, takes variation into account.

In this experiment, ANOVA will be applied to experimental situations utilizing orthogonal arrays, although this analysis method can be used with any set of data that has some structure. The experimental designs and subsequent analyses are intrinsically tied to one another.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Oxford dictionary define methodology as procedure or way of doing something. In spite of that, two main categories are made in this study method which is turning experiment and analysis of a result.

In the turning experiment we will focus on the cutting experiment from the start of the experiment till we got the surface finishes results. After we get a result, project will continue on analysis of the result to find an optimal cutting parameter for surface roughness. In the end of the project, confirmation test are used to verify the results. The flowchart been made to give us the guidelines and direction to make the process successfully. The Taguchi method flowchart is shown in Figure 3.1

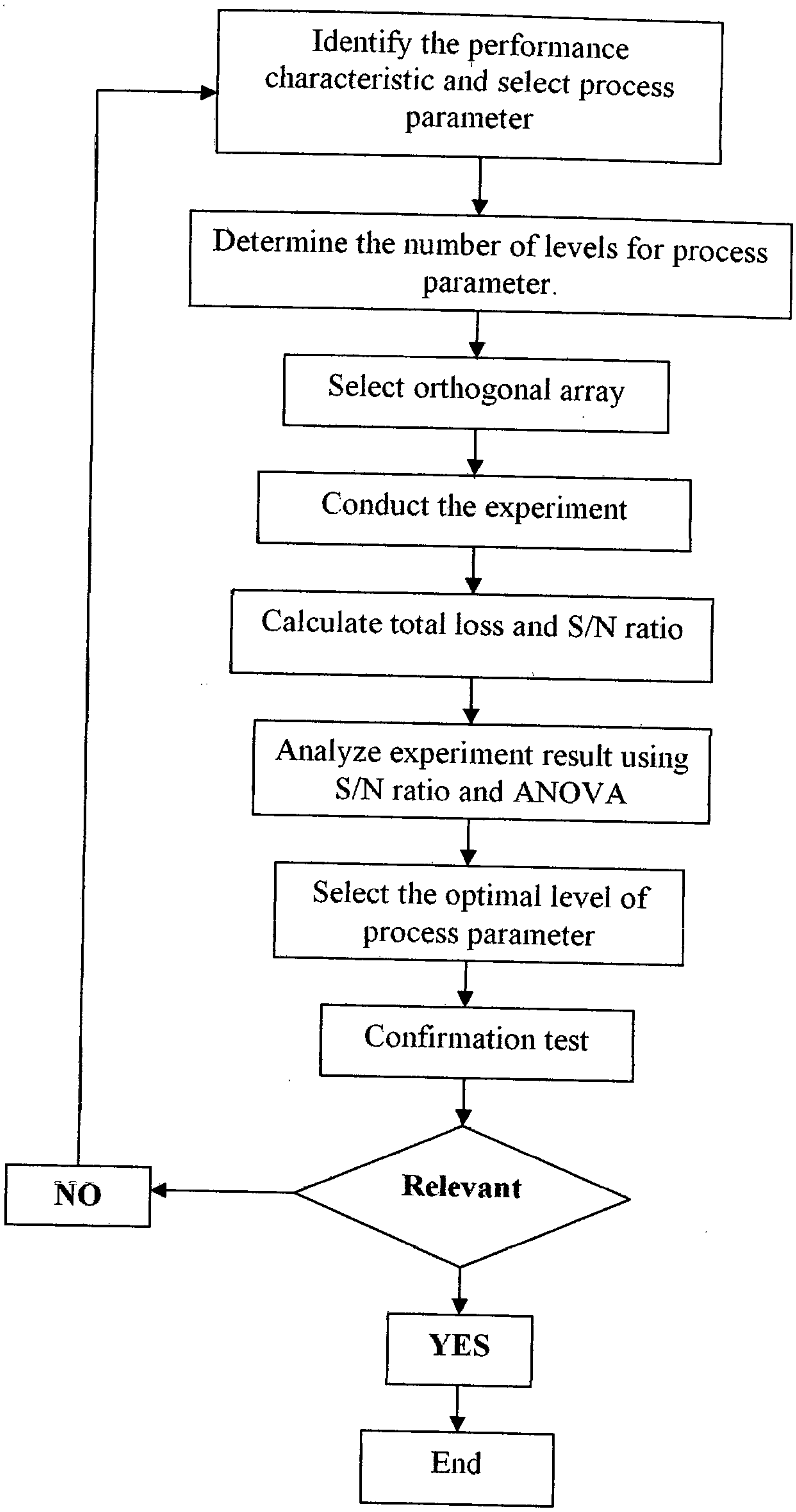

Figure 3.1 Taguchi method flow chart

3.2 Turning experiment

Turning experiment starts with choosing the right cutting parameters and levels. After that, an appropriate orthogonal array to reduce the number of cutting experiments for determining the optimal cutting parameters is reported. The results from the cutting experiment are measured by the surface roughness indicator.

3.2.1 Selection of cutting parameters and their levels

After some discussion with supervisor and lab coordinator, it's decided that the cutting experiment will be carried out on a NEF 400 Gildemeister CNC turning lathe machine with the AISI 1030 steel bar as a work piece material. In the test used inserts were TNMG1600404-MA, TNMG160408-MA and TNMG160412-MA. Mechanical properties and chemical composition of AISI 1030 carbon steel which was used in the experiments as shown in table 3.1 and table 3.2, respectively. The feasible range for the cutting parameters was recommended by a machining handbook, i.e., insert radius in the range 0.4-1.2 mm, feed rate in the range 0.15-0.35mm/rv, and depth of cut in the range 0.5-2.5 mm. Therefore, three level of the cutting parameter were selected as shown in table 3.3.

Table 3.1 Mechanical properties of AISI 1030 carbon steel

Elongation (%)	Hardness (HB)	Tensile strength (MPa)	Yield strength (MPa)	Thermal conductivity (W/m K)
31.2	126	463.7	341.3	51.9

Table 3.2 Chemical composition of AISI 1030 carbon steel, % weight

C	Si	Mn	P	S
0.276	0.11	0.61	0.04	0.05