Multi-Objective Optimization in CNC Turning of S45C Carbon Steel using Taguchi and Grey Relational Analyses

By

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CNC	Computer Numerical Control
MRR	Material Removal Rates
TW	Tool Wear
GRA	Grey Relational Analysis
GRG	Grey Relational Grade
GRC	Grey Relational Coefficients
DOE	Design of Experiment
ANOVA	Analysis of Variance
PCD	Poly Crystalline Diamond
CBN	Cubic Boron Nitride
S/N	Signal to Noise
SEM	Scanning Electron Microscopy
HABC	Hybrid Artificial Bee Colony
RSM	Response Surface Methodology
PCA	Principal Component Analysis
GFRP	Glass Fiber Reinforced Polymer
WEDM	Wire Electrical Discharge Machining
HAZ	Heat Affected Zone

Pengoptimuman Multi-Objektif di dalam Proses CNC Turning S45C Keluli Karbon Menggunakan Kaedah Taguchi dan Grey Relational Analyses

ABSTRAK

Terdapat pelbagai jenis proses pemesinan yang telah diperkenalkan sejak dahulu lagi akan tetapi masih digunakan sehingga ke hari ini. Dari masa ke semasa, para penyelidik tidak pernah berhenti daripada mencari peningkatan dari setiap aspek. Salah satu proses pemesinan yang terkenal dan selalu digunakan adalah proses melarik. Menariknya, pengoptimuman ciri-ciri prestasi tunggal telah berjaya dilaporkan oleh kebanyakan penyelidik. Walau bagaimanapun, pengoptimuman multi-objektif adalah lebih sukar dan mencabar untuk dikaji kerana kerumitannya. Ini adalah kerana, peningkatan terhadap sesuatu ciri prestasi akan menyebabkan pengurangan kepada ciri prestasi yang lain. Sehubungan dengan itu, kajian berkaitan pengoptimuman multi-objektif menggunakan S45C keluli karbon dengan kaedah Taguchi dan Grey Relational Analysis (GRA) telah dilaporkan di dalam disertasi ini. Berdasarkan kepada kaedah Grey Relational Analysis, nilai Grey Relational Grade (GRG) dikira untuk mengoptimumkan parameter proses melarik dengan pelbagai ciri prestasi seperti kekasaran permukaan, kadar pembuangan bahan, kerosakan mata alat dan penggunaan kuasa oleh mesin.Dalam kajian ini, dua parameter penting telah dipilih, iaitu spindle speed dan feed rate manakala nilai kedalaman pemotongan telah dimalarkan. Suatu reka bentuk kaedah eksperimen telah digunakan untuk menentukan hubungan antara parameter pemesinan dan ciri prestasi. Melalui kaedah ini, kombinasi terbaik yang diperoleh adalah pada spindle speed 3000 RPM dan feed rate 0.2 mm/rev dan keputusan dari ANOVA menunjukkan spindle speed adalah pengaruh terbesar dalam perubahan ciri-ciri prestasi dengan peratus penyumbangan sebanyak 68.60% . Hasil dari kajian ini akan memberi manfaat dari segi pengetahuan di antara parameter pemesinan dan juga ciri-ciri prestasi.

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ABSTRACT

There are various types of machining process that have been introduced long time ago and yet still be used until now. From time to time, researchers have never stop in seeking for an improvement for these processes in every aspect. One of the famous machining processes that are commonly used is turning process. Interestingly, the optimization of single performance measures has been successfully reported by many of the researchers. However, the multi-objective optimization is more difficult and challenging to be studied due to its complexity. This is because an improvement of one performance measure may lead to degradation of other performance measure. In response to that, the study of multi-objective optimization in CNC turning of S45C carbon steel by using Taguchi and Grey Relational Analysis (GRA) method has been reported in this study. Based on grey relational analysis, a grey relational grade (GRG) is computed to optimize the machining parameters of CNC turning process with multiple performance measures which is surface roughness, material removal rate (MRR), tool wear and power consumption of the machine. In this study, two important parameters have been selected, namely spindle speed and feed rate while the depth of cut was set at fixed value. A design of experiment methodology was employed to determine the relationships between machining parameters with the performances measures. Through this method, the best setting parameter was found at spindle speed of 3000 RPM and feed rate of 0.2 mm/rev and results from ANOVA shows that spindle speed is the main contributor to the change of performance measures with almost 70% contribution. The findings from this study will benefit in term of knowledge between the machining parameters with the performance measures.

CHAPTER 1

INTRODUCTION

1.1 Background

Turning operation is one of the most utilised methods in metal removing process, especially to produce conical or cylindrical parts. Various types of part geometries can be produced by lathe machine, which includes flat surfaces, curved surfaces, grinding, and boring. Is it well known that the mechanism of material removal in turning operation is through the creation of chips from workpiece material using sharp edge cutting tool. This mechanism allows the finished product to be obtained with desired geometrical and performance measures. The crucial performance measures that are frequently being monitored in turning process are surface roughness, material removal rate (MRR), tool wear, and power consumption. An ideal turning process should produce product with good surface roughness, high MRR, minimal tool wear as well as low in the power consumption.

In response to these requirements, the current issue of turning process is to determine the optimal machining parameters in order to improve the aforementioned performance measures simultaneously (Lin, 2004). The machining parameters that directly contribute towards the output performance measures are spindle speed, feed rate, and depth of cut. However, most of the current methods employed are only applicable for single performance measures optimization. As a matter of fact, single optimization in turning operation is only focusing on one performance measures at a time. This is due to the fact that this is easier to be carried out because improvement can be done without concerning about the effect of the other outputs. However, in multi-objective optimization, all performance measures need to be considered and improved at the same time or simultaneously. Therefore, it is often difficult and challenging to select machining parameter settings that can provide ideal performance for all the response simultaneously.

It is to note here that the most common method used in machining research employs Design of Experiment (DOE) technique, which is Taguchi method (Montgomery, 2008; Rodrigues et al., 2012; Tzeng, 2009). Taguchi Method has been identified and proved as an effective design of experiment approach that aims to produce high quality product at relatively lower cost (Ross, 1988; Fowlkes & Creveling, 1995). It has also been successfully applied by other researchers to optimize multiple performance measures in other research domains. However, the original design of Taguchi method is to optimize a single output measures (Nalbant, 2007). The improvements of multiple-performance measures can sometimes become challenging because each of the performance measures has their own characteristic. For example, MRR employs the "higher-the-better" performance measure, while surface roughness, tool wear, and power consumption employ the "lower-the-better" characteristic. Therefore, improvement of one performance measure may lead to the degradation of another performance measure.

Thus, for multiple-performance measures, another method can also be implemented along with Taguchi's method, which is known as Grey Relational Analysis (GRA). Interestingly, GRA is applied by combining several of performance measures into a single value, which known as Grey Relational Grade (GRG). By applying this method, the multi-performance measure can be converted into a single GRG. In other words, the complicated multi-performance measure is now simplified into a single value to allow the optimization process become easier and efficient.

1.2 Problem Statement

In order to produce a good quality product at a minimal cost, every manufacturer seeks for a low surface roughness, low tool wear, high MRR, and minimum power consumption in turning process. All of these outputs are the most critical responses in turning process that must be taken into consideration. However, the selection of machining parameters such as cutting speed and feed rate are the most challenging part as they directly contribute to the performances measure of product being produced. It is often difficult to select machining parameters setting, which can provide good performance for all of the response simultaneously. Most of the parameter selection can optimize either one of these outputs only at one time. Therefore, this study will propose the best combination of machining parameter that can improve all four performance measures; namely, surface roughness, MRR, tool wear, and power consumption simultaneously by using combination of Taguchi and Grey Relational Analysis methodologies.

1.3 Research Objectives

The objectives of this research are:

i. To investigate the effects of machining parameters on individual performance measures while turning S45C carbon steel

ii. To determine the best combination of machining parameters considering multiple performance measures using Grey Relational Analysis

1.4 Scopes and Limitations

The scopes and limitations in this research are stated as below:

i. Turning process with S45C carbon steel as the workpiece

ii. Turning process using uncoated tungsten carbides cutting tool

iii. Turning process is performed under dry condition

1.5 Dissertation Outlines

This dissertation consists of five main chapters. The first chapter of this dissertation describes the general introduction of this study. This includes the problem statements, research objectives as well as the scopes and limitations.

Chapter 2 presents literature review on solutions proposed by previous researchers for multi-objective optimization and methods employed. Then, it is followed with the systematic review on the applications of GRA, which has been successfully demonstrated on various types of multi-objective problems. After that, the reviews continue with the findings of other researchers on performance measures; namely, MRR, surface roughness, tool wear and power consumption.

Chapter 3 explains about the experimental procedure used for this study. The explanations include the selection of materials and cutting tool. All the machines used for data acquisition are also presented in this chapter. The discussion continues with the explanation about the research approach.

Chapter 4 discusses about the results obtained in this study. The discussion starts with the four main performances measure single characteristics; namely, MRR, surface roughness, tool wear and power consumption of the turning operation. The chapter continues with the result of Grey Relational Analysis (GRA) followed with the statistical analysis of variance (ANOVA). At the end of this chapter, the best combinations of machining parameters have been successfully identified.

The final chapter of this dissertation, Chapter 5, summarizes and concludes the findings of this study. This chapter also describes the contributions of this study and recommendation for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents the literature reviews that has been carried out based on methods in solving multi-objective optimization and followed by reviews on output responses selected in this study.

2.2 Methods in CNC turning optimization

These sections are divided into two parts. The first part is to study the previous researcher methods in solving the multiple optimizations problems. Second part focuses on the method of applying Taguchi method and Grey Relation Analysis in optimizing various types of machining process.

2.2.1 Review of methods in solving multiple objectives optimization problem

It is well known that the major cutting parameters for turning process are spindle speed, feed rate and cutting depth. However, it is essential that the best settings for these controlled parameters being determined in order to ensure effective and efficient machining processes in industries. There are a number of methods that have been proposed by researchers in order to optimize the cutting parameters for turning process. For example, a combination or hybrid Taguchi-Fuzzy has been used to determine the optimum parameter for high speed CNC turning of AISI P-20 tool steel. Gupta et al. (2011) has found that this newly developed method is very useful in improving multiple performance measures such as surface roughness, tool life, cutting force and power consumption in high speed CNC turning. However, this method was too complicated and was claimed to be only suitable for high speed machining.

Besides Taguchi-Fuzzy method, the determination of optimal cutting parameters can be done by using another multi-objective technique, which is based on genetic algorithms. As proposed by Sardinas et al. (2006), two objectives, tool life and operation time can be simultaneously optimized. This model used a micro-genetic algorithm in order to obtain the non-dominated points and build the Pareto front graph. This Pareto front graph information was claimed to assist the decisions making process for the machining process investigated. However, this model must be enlarged to include more constraint such as cutting surface temperature to improve its accuracy (Sardinas et al., 2006).

Desirability function is another method to optimize multiple performance measures in CNC turning process. In 2008, Aggarwal et al. (2008) has carried out experiment in CNC turning of AISI P20 tool steel using liquid nitrogen as a coolant. A face centered central composite design was used in this experiment. From the investigation, they have found that at higher a value of feed rate; the cutting force, power consumption and surface roughness will be high and the tool life will be shorter. Likewise, at higher cutting speed, power consumption is high and tool life will be shorter (Aggarwal et al., 2008).

Another method is the Hybrid Artificial Bee Colony (HABC) algorithm based approach that has been studied for the optimization of cutting parameters in the multi-pass turning operations. This method was investigated and proved by Yildiz (2013), in order to minimize the unit production cost in multi-pass turning operation. The improvement has been confirmed through comparison of results between HABC against other techniques in tabular form. The results showed that the HABC was highly competitive compare to other algorithms for solving the multi-pass turning optimization problems (Yildiz, 2013).

An alternative hybrid approach, the combination of Response Surface Methodology (RSM) and Principal Component Analysis (PCA) has been proposed by Paiva et al. (2007) to optimize the multiple correlated responses in turning process. The turning process of AISI 52100-hardened steel was examined by considering three cutting parameters; namely cutting speed, feed rate and depth of cut. The outputs considered were tool life, processing cost per piece, cutting time, total cycle time, surface roughness and material removal rate (MRR). Through the method, they have found that the multi-response optimization was achieved at the cutting speed of 238 m/min, with feed rate of 0.08 mm/rev and at depth of cut of 0.32 mm (Paiva et al., 2007).

2.2.2 Review on the applications of Taguchi and Grey Relational Analysis methodologies

Multi performance measure optimization using Taguchi-Grey methodologies for turning process was initially studied and reported by Lin et al. (2004). The cutting speed, feed rate and depth of cut were chosen as the cutting parameters to improve tool life, cutting force and surface roughness. At the end of the study, the authors have found out that the performance measures of turning process can be improved. It was reported that feed rate contributed the most to the changes of performance measures compared to cutting speed and depth of cut (Lin et al., 2004).

Besides turning process, application of Taguchi-Grey methodologies has also been proposed by Azmi (2012) to optimize the performance measures of glass fiber reinforced polymer (GFRP) composites in end milling. In his study, Grey Relational Analysis was employed to solve multiple performance measures of tool life, machining forces and surface roughness. The results showed that feed rate has the most significant influence on the multiple performance measures. Through confirmation test, the author also reported that the Taguchi-Grey analysis can be effectively used to determine the multiple performance measures and consequently improved the end milling of GFRP composites.

The optimization of machining parameters for wire-electrical discharge machining (WEDM) using Grey Relational Analysis was conducted by Huang and Liao (2003). By using both Grey relational analysis and a statistical method, they have found that feed rate has a significant influence on the metal removal rate, whilst the gap width and surface roughness were mainly influenced by pulse on time. As the conclusion, they have mentioned that the optimal machining parameters' setting for maximum metal removal rate and minimum surface roughness could be determined by Grey Relational Analysis.

Meanwhile, Çaydaş and Hasçalık (2008) has proposed the optimization of laser cutting process of St-37 steel with multiple performance measures. In their study, the laser cutting parameters such as laser power and cutting speed were optimized with consideration of multiple-performance measures, such as workpiece surface roughness, top kerf width and width of Heat Affected Zone (HAZ). Through grey relational analyses, they have found that the laser power was more significant on the responses rather than cutting speed. They also have proved that the performance measures in laser cutting process can be improved effectively by using this approach.

2.3 Performance measures

This section presents the review on all four main performance measures selected in this study. The four performance measures are MRR, surface roughness, tool wear and power consumption. The review includes the methods and formula used to calculate corresponding performance measures.