UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF FUZZY LOGIC MODEL FOR TURNING PROCESS OF STEEL ALLOY AND TITANIUM ALLOYS

TAN JIT YEAN

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By

TAN JIT YEAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia in Fulfilment of the Requirements for the Degree of Master of Science

November 2004

Dedicated with love and gratitude to

My dearest parent, lover, family and friends

as

my source of encouragement and support in completion of this study

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science

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Chairman : Wong Shaw Voon, Ph.D.

Faculty : Engineering

The study is about the application of fuzzy logic in representing the machinability data for the turning process. Machining is a very complex process with respect to the influences of the machining parameters such as cutting speed, feed rate, and depth of cut. In order to perform a good machining practice the proper selection of the machinability data, which includes the machining parameters and cutting tools is very important. Normally, the selection of the machinability data is done by the skilled machinist. The manufacturer may face trouble without the presence of the skilled machinists. Thus, there is a necessity to represent the knowledge of the skilled machinists into model, so that any normal machinists will be able to perform a good machining practice by retrieving the information which prescribed in the model. Consequently, fuzzy logic was chosen as a tool to describe the strategy and action of the skilled machinist.

In this study, two types of fuzzy models for different workpiece material have been developed, and they are alloy steel and titanium alloys fuzzy models. Both fuzzy models serve the purpose of predicting the appropriate cutting speed and feed rate

with respect to the corresponding input variables. Generally, the development of fuzzy model involves the design of three main elements, which are inputs membership functions, fuzzy rules (inference mechanism), and output membership functions. So far, there is no any clear procedure that can be used to develop these three elements. Thus, the strategy for generalizing the development of alloy steel fuzzy model has been suggested. This strategy is useful and less effort is required for developing a related new fuzzy models.

The design of fuzzy rules is always the difficult part in developing the fuzzy model due to the tedious way of defining fuzzy rules with the conventional method. Therefore, a new method of developing fuzzy rules, namely fuzzy rule mapping has been introduced and implemented. Through fuzzy rule mapping method, the effort and the time required in developing the fuzzy rules has been reduced. This method has been applied in the developing the fuzzy model for alloy steel.

All the predicted outputs (cutting speed and feed rate) from the alloy steel (with general strategy and fuzzy rule mapping) and titanium alloys fuzzy models were being compared with the data obtained from "Machining Data Handbook", by Metcut Research Associate, and a good match have been obtained throughout the comparison. The average percentage errors for alloy steel fuzzy models with the implementation of general strategy and fuzzy rule mapping are about the ranges of 3.1% to 5.6% and 3.0% to 10.7%, respectively. On the other hand, the average percentage error for titanium alloys fuzzy model is about 1.8% to 5.1%. These results have showed that the machinability data information for the turning of alloy steel and titanium alloys can be represented by fuzzy model. Besides that, it has also proved the feasibility of using the suggested strategy and fuzzy rule mapping method.

Abstrak thesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PEMBANGUNAN MODEL FUZZY LOGIK BAGI PROSES MELARIK KELULI ALOI DAN ALOI TITANIUM

Oleh

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Kajian ini adalah mengenai penggunaan logik fuzzy bagi mewakili pemilihan data kebolehmesinan bagi proses melarik. Pemesinan ialah satu proses yang sangat komplek dengan adanya parameter pemesinan seperti kelajuan pemotongan, kadar suapan, dan kedalaman pemotongan. Untuk menjalankan proses pemotongan yang memuaskan, pemilihan data kebolehmesinan yang sesuai adalah sangat penting. Biasanya pemilihan data kebolehmesinan dilakukan oleh jurumesin mahir. Pihak pengilang mungkin menghadapi masalah untuk menjalankan praktis pemotongan yang bagus sekiranya kekurangan jurumesin mahir. Dengan itu, adalah penting dan perlu untuk mewakilkan pengetahuan jurumesin mahir dalam bentuk model, dan diharapkan jurumesin biasa mampu menjalankan praktis pemesinan yang bagus melalui maklumat yang diperolehi daripada model. Malangnya, pemilihan data kebolehmesinan tidak boleh diformula ke sebarang model matematik dengan mudah. Oleh yang demikian, logik fuzzy telah dipilih sebagai alat untuk menerangkan strategi dan tindakan jurumesin mahir.

Dalam kajian ini, dua jenis model fuzzy dengan bahan yang berlainan telah dibina, iaitu, model fuzzy keluli aloi dan aloi titanium. Kedua-dua model fuzzy ini mempunyai tujuan untuk menganggarkan kelajuan pemotongan dan kadar suapan yang optima dengan adanya input yang berkenaan. Secara umumnya, pembinaan model fuzzy melibatkan perekaan bagi 3 elemen, iaitu input fungsi keahlian, penggaris fuzzy, dan output fungsi keahlian. Kini, tiada sebarang prosedur yang jelas untuk membina model fuzzy. Dengan itu, suatu strategi simpulan keseluruhan telah dicadangkan dan dilaksanakan bagi pembinaan model fuzzy keluli aloi. Strategi tersebut adalah berguna dan dapat memudahkan kerja pembangunan sebarang model fuzzy baru yang berhubungan.

Pembinaan penggaris fungsi adalah suatu tugas yang sukar disebabkan oleh cara pembinaan penggaris fuzzy yang meletihkan. Oleh itu, cara baru bagi pembinaan set penggaris fuzzy, dan ia dinamakan "Pemetaan Penggaris Fuzzy" (Fuzzy rule mapping) telah dikemukakan bagi memudahkan kerja pembinaan penggaris fungsi. Dengan adanya cara tersebut, usaha dan juga masa yang diperlukan bagi pembinaan penggaris fuzzy dapat dikurangkan. Pemetaan Penggaris Fuzzy ini telah digunakan dalam pembentukan model fuzzy keluli aloi.

Kesemua output anggaran daripada model fuzzy keluli aloi (dengan menggunakan strategi simpulan keseluruhan dan Pemetaan Penggaris Fuzzy) dan aloi titanium akan dibanding dengan data yang diperolehi daripada "Buku Panduan Data Pemotongan", oleh Metcut Research Associate, dan korelasi yang baik telah dipaparkan di seluruh perbandingan. Di mana, peratus kesilapan untuk model fuzzy alloy steel dengan penggunaan strategi simpulan keseluruhan dan Pemetaan Penggaris Fuzzy adalah di antara 3.1% hingga 5.6% dan 3.0% hingga 10.7%, masing-masing. Di samping itu, peratusan kesilapan untuk model fuzzy titanium alloys adalah di antara 1.8% hingga 5.1%. Keputusan in menunjukan bahawa, pemilihan data keupayaan proses pemutaran bagi keluli aloi dan aloi titanium dapat diwakili oleh model fuzzy. Selain daripada itu, ia juga membuktikan kepenggunaan strategi simpulam keseluruhan dan juga Pemetaan Penggaris Fuzzy.

ACKNOWLEDGEMENTS

First of all, I would like to express my heartiest gratitude and appreciation to my supervising committee chairman, Associate Professor Dr. Wong Shaw Voon, Faculty of Engineering, University Putra Malaysia (UPM) for invaluable advice and untiring assistance in this master research. His constant guidance, support and encouragement were the motivations that enabled me to accomplish my study.

Great thanks to committee members Associate Professor Dr. Napsiah Ismail, head of Mechanical and Manufacturing Engineering Department, UPM, and Associate Professor Dr. Abdel Magid Salem Hamouda for their constructive suggestion, proper guidance and encouragement throughout my study period.

This multidisciplinary study could not have been accomplished without the financial support from Intensification of Research in Priority Area (IRPA) programme, provided by the Ministry of Science Technology and Innovation (MOSTI).

Special thanks also goes to my colleagues and friends, who in one way or another have support, assistance and gave me courage to proceed to completion. Last but not least, my deepest thanks to my family members, especially my parent for their continued support.

I certify that an Examination Committee met on 29th November 2004 to conduct the final examination of Tan Jit Yean on his Master of Science thesis entitled "Development of Fuzzy Logic Model for Turning Process of Steel Alloy and Titanium Alloys" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

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TAN JIT YEAN

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LIST OF ABBREVIATIONS

CNC	Computer Numerical Control
AI	Artificial Intelligent
GOL	Genetic Optimization Library
EXCATS	Expert Computer Aided Cutting Tool Selection
CAD	Computer Aided Design
IGES	Initial Graphic Exchange Specification
CAPP	Computer Aided Process Planning
MIA	Multiple-Input Averaging
MAPE	Mean Absolute Percentage Error

CHAPTER 1

INTRODUCTION

Machining is one of the important processes in a manufacturing system. It serves the purpose of generating a desired shape of the workpiece from a solid body, and it can also be performed to improve the tolerances and surface finish of a previously form of workpiece. This process involves the removal of the excessive material from the workpiece in the form of chips. Generally, machining is capable of producing geometric configurations, tolerances, and surface finishes, which are normally difficult to obtain by any other technique. However, machining removes the material which has already been paid, and the chips produced are relatively small, thereby causing difficulties in recycling. Thus, the manufacturers try to reduce the process of machining, especially in mass production. Because of this, machining has lost some of the important application areas. Meanwhile, as the development of machining technology has kept growing, the new technology, called computer numerical control (CNC) has been introduced, and this enables machining to capture the new application areas.

Machining process is very complex with respect to the influences of the machining parameters, such as the cutting speed, feed rate, and depth of cut. It is closely related to the machinability data which includes the proper selection of cutting tools and machining parameters. The selection of machinability data has played an important role in the effectiveness of machine tool utilization, which directly influences the overall manufacturing cost. The influences of the machining parameters on machine tools are not always precisely known and hence, it becomes difficult to recommend the optimum machinability data for machining process. Consequently, the selection of the machinability data is normally done by a skilled machinist, who will make the decision based on their experience and intuition. Through the experience gained over the years, skilled machinist possesses certain empirical rules and guiding principles for choosing the optimum machinability data. Another method which is the most widely used source of obtaining machinability data is the "Machining Data Handbook" [1]. The handbook recommends the cutting speed and feed rate given a particular depth of cut, material hardness, and cutting tool.

Artificial intelligence (AI) is concerning with a system that is capable of exhibiting the characteristics of a human behaviour, such as the ability of learning, reasoning, problem solving. The aim of artificial intelligence is to simulate the human behaviour on the computer, and it can be experimental knowledge (expertise) or basic description of fact [2]. Nowadays, the term AI has gain popularity due to the successful application of its concept in many common commercial products.

Expert system is one of the elements of artificial intelligence, and it is also known as knowledge-based system. The expert system or knowledge-based system can be defined as an intelligent computer program that possess the ability to capture the specific knowledge of a particular domain, and imitate the problem solving strategies of human experts to provide the recommendations [3]. In other words, an expert system is capable of performing an intellectually demanding task as well as a human expert. They represent a new problem solving paradigm that utilizes many techniques developed from AI research. An expert system possesses the capacity for a heuristic approach, which is, making a good judgement and good guess just like the an expert [2].

Another common element of artificial intelligence is fuzzy logic. Generally, the word "fuzzy" can be defined as blurred; imprecisely defined; confuse or vague. Hence, fuzzy logic is defined as the mathematical means of representing vagueness and imprecise information. Fuzzy logic has today become one of the widely used technologies due to its successful application in many controlling systems. It is so widely used because of its ability in representing the vagueness and imprecise information. It is very suitable in defining the relationship between a system inputs and desired system outputs [4]. It is also popular for its ability to develop rule-based expert system. Fuzzy controllers and fuzzy reasoning have found particular applications in very complex industrial systems that cannot be modelled precisely even under various assumptions and approximations [5]. The control of such systems by experienced human operators was proven in many cases to be more successful and efficient compared to the classical automatic controllers. The human controllers employ experiential rules that can be cast in the fuzzy logic model. These observations inspired many investigation and research works in this area, thus, fuzzy logic and fuzzy rule-based control system have been developed [4].

Fuzzy logic was introduced by Zadeh [6] in his pioneering work in the middle of 1960s. The exploration of fuzzy logic was then followed by Mandani [7] who has applied the concept of fuzzy logic in modelling and controlling the pressure for a small boiler. Recently, the concept of fuzzy logic has also been applied to prescribe the machining process, where, El Baradie [8] has developed the first fuzzy model for machinability data selection of carbon steel for the turning process. The works were then extended by Wong *et al*. [4], where a new fuzzy model for machinability data selection of carbon steel has been developed. Later, similar types of fuzzy models have been developed for representing the turning process of alloy steel [9].

1.1 Problem Statement

The optimum performance and the effectiveness of the machining process always depend on the proper selection of machinability data. In fact, the selection of machinability data is not an easy task and not always precisely known due to the complexity of the machining process. Therefore, it becomes very difficult to achieve the optimum performance when machining. Even though there is a good source for obtaining machinability data, which is through the "Machining Data Handbook" [1], but the recommended data can only be considered as a good starting point. This is because of the influence from other variable such as part configuration, machine condition, type of fixture, dimensional tolerance and surface roughness. In this case, the selection of the machinability data can be carried out by a skilled machinist who will decide the appropriate turning parameters based on the knowledge and experience gained over the years. Therefore, there is a necessity to cast the knowledge of the skilled machinists into a model. Hence, fuzzy model has been developed to describe the machinability data selection due to its ability in representing vague and imprecise information.

Generally, the development of fuzzy model involves the design of 3 elements, and they are the input membership function, fuzzy rule, and output membership function.