Faculty of Manufacturing Engineering

ARTIFICIAL NEURAL NETWORK MODELLING TO PREDICT LASER MICRO GROOVING QUALITY OF COMMERCIALLY PURE TITANIUM GRADE 2

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DECLARATION

I declare that this thesis entitled "Artificial Neural Network Modelling to Predict Laser Micro Grooving Quality of Commercially Pure Titanium Grade 2" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is concurrently submitted in candidature of any other degree.

Signature: _____

Name : Abdul Zuhair Bin Abdul Khalim

Date : _____

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Doctor of Philosophy.

Signature : _____

Supervisor Name: Professor. Ir. Ts. Dr. Sivarao Subramonian

Date : _____

DEDICATION

To my beloved mother and late father

ABSTRACT

Grooving is the process of making a narrow channel on a surface of flat or cylindrical workpiece. Often it is performed on workpiece shoulders to ensure the correct fit for mating parts. Groove is widely used in automotive industry, biomedical implants and electronic devices. Though, laser machining is known as advanced machining process is an alternative machining used by high precision industries as cutting tool. Due to its ultra-flexibility, high quality end product, tight tolerance, quick set up, high repeatability, and many other advantageous, it is being widely accepted and explored for it potential in machining industries. Unfortunately, machining of groove especially micro-groove by traditional machining is very much challenged in dimensional control due to mechanical contact. A micro groove is a basic geometric feature of a micro part. The disadvantages of traditional machining become much severe when it deals with micro-grooving where, not only the external dimensions, but also the metallurgy of the end product is being affected. Although laser lathing is available, it is very complex and expensive where most commonly used in the industries are flat stock laser machining. Thus, an existing 4 by 8 feet 3KW CO_2 flatbed laser cutting machine has been transformed to perform laser lathing. The transformation of 2D flatbed laser cutting machine into 3D laser cutting ability is explored of its performance in producing micro-grooves on a Titanium Grade 2. This research work presents the modelling study of micro-grooving in laser machining of commercially pure titanium grade 2 material with CO_2 laser by considering the power, gas pressure, cutting speed, depth of cut and focal distance as the designed process parameters. This research focuses on experimental of laser micro-grooving quality and development of artificial neural network (ANN) model. The experimental plans were conducted according to the design of experiment (DOE) to accommodate full range of experimental analysis. Therefore, three significant responses namely groove depth, groove width and groove corner radius were investigated to fall within desired values. Analysis found that an experimental error such as the discovery of an unknown effect, inherent variability in the system, inability to control complex variables, temperature or unexpected mechanical machining tolerance have influenced the predictive model. Two types of model are introduced which are namely singleton output model and multiple output model. The results indicate that, there is a difference of 2% between the two models. Therefore the significant error in predictive model occur due to the factors of pattern recognition. However, the developed ANN model is found valid through data testing where the mean absolute percentage error (MAPE) is less than 20 per cent.

PEMODELAN RANGKAIAN NEURAL BUATAN UNTUK MERAMAL KUALITI LASER ALUR MIKRO BAGI TITANIUM TULEN KOMERSIAL GRED 2

ABSTRAK

Pengaluran adalah proses membuat saluran sempit pada permukaan bahan kerja datar atau silinder. Selalunya ia dilakukan pada bahu bahan kerja untuk memastikan bahagian yang sesuai untuk pemasangan. Alur biasanya digunakan dalam industri automotif, implan biomedikal dan alat elektronik. Walaupun pemesinan laser yang dikenali sebagai proses pemesinan canggih adalah pemesinan alternatif yang digunakan oleh industri berketepatan tinggi sebagai alat pemotong. Oleh kerana kelenturannya yang ultra-fleksibel, produk akhir berkualiti tinggi, toleransi yang ketat, persediaan pantas, kebolehulangan yang tinggi, dan lain-lain yang berfaedah, ia diterima secara meluas dan diterokai kerana ia berpotensi dalam industri pemesinan. Malangnya, pemesinan alur terutamanya mikro-groove oleh pemesinan tradisional sangat mencabar dalam pengawalan dimensi kerana sentuhan mekanikal. Alur mikro adalah ciri geometri asas bahagian mikro. Kelemahan pemesinan tradisional menjadi lebih parah apabila ia berkaitan dengan mikro-grooving di mana, bukan sahaja dimensi luaran, tetapi juga metalurgi produk akhir juga terjejas. Walaupun laser larik tersedia, ia sangat komplex dan mahal dimana yang paling biasa digunakan dalam industri adalah laser pemesinan rata. Oleh itu, mesin pemotong laser 3kW CO_2 yang sedia ada telah diubah untuk melakukan pemotongan laser. Transformasi mesin pemotong laser 2D kepada keupayaan pemotongan laser 3D diterokai mengenai prestasinya dalam menghasilkan mikro-alur pada Gred Titanium 2. Kajian penyelidikan ini membentangkan pemodelan mikro-grooving dalam pemesinan laser titanium komersil tulen (CP) gred 2 dengan laser CO_2 dengan mempertimbangkan kuasa, tekanan gas, kelajuan pemotongan, kedalaman pemotongan dan jarak fokus sebagai proses parameter. Penyelidikan ini memfokuskan pada eksperimen kualiti alur mikro laser dan pembangunan model rangkaian neural tiruan (ANN). Pelan eksperimen dijalankan mengikut reka bentuk eksperimen (DOE) untuk menampung pelbagai analisis eksperimen. Oleh itu, tiga tindak balas yang signifikan iaitu kedalaman alur, lebar alur dan jejari sudut alur disiasat supaya berada dalam nilai yang diingini. Analisis mendapati bahawa kesilapan eksperimen seperti penemuan kesan yang tidak diketahui, kebolehubahan yang wujud dalam sistem, ketidakupayaan untuk mengawal pemboleh ubah kompleks, suhu atau toleransi pemesinan mekanikal yang tidak dijangka telah mempengaruhi model ramalan. Dua jenis model diperkenalkan iaitu model output tunggal dan model keluaran berganda. Hasil kajian menunjukkan bahawa, terdapat perbezaan 2% antara kedua model tersebut. Oleh itu kesilapan yang ketara dalam model ramalan berlaku disebabkan oleh faktor pengecaman corak. Walau bagaimanapun, model ANN yang dibangunkan didapati sah melalui pengujian data di mana ralat peratusan mutlak (MAPE) kurang dari 20 peratus.

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LIST OF ABBREVIATIONS

ANN - Artificial neural network

CCD - Central composite design

CO_2 - Carbon Dioxide

DOE - Design of experiment

H2 - Hydrogen

HAZ - Heat affected zone

He - Helium

MAPE - Mean absolute percentage error

n.d - No date

N2 - Nitrogen

Nd:YAG - Neodymium-doped yttrium aluminum garnet

RSM - Response surface methodology

Xe - Xenon

LIST OF PUBLICATIONS

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CHAPTER 1

INTRODUCTION

1.1 Research background

Manufacturing is the process of producing product from raw material by using various equipment such as hand tools, machinery or even computers. In other words manufacturing is the application of physical and chemical processes to alter the geometry, properties or appearance of a given raw material to become parts or product. Manufacturing is divided into several major processes and one of the processes is machining. Machining is the process of removing undesired or unwanted material from the workpiece to produce required shape using a cutting tool.

One of the most regular machining operations is turning. Turning is the process of machining external, or internal cylindrical and conical surfaces in which the part is rotated as the tool is held against it on a machine called a lathe. Mathematically, each surface that is machined on a lathe is the surface of revolution. Those among the turning job is grooving. Grooving is the process of cutting a narrow groove on the cylindrical surface of the workpiece. It is often done on workpiece shoulders in ensuring the correct fit for mating parts.

Today, most of the components are manufactured in accordance with the current requirements such as micro-grooves. A micro-groove is a basic geometric feature of a micro part. Micro-grooves is a prominent microstructure in micro instruments, and have been well applied in various industrial advanced applications such as biomedical, microelectronic, and aerospace (Chen et al., 2016). Figure 1.1 shows some of micro-groove applications which is

applied on the biomedical and electronic device. In line with the demand of material and machining parameter, grooving using traditional machining especially turning is impossible to be achieved. However, the advancement of machining technology is viewed as an option to traditional machining. Therefore, non-traditional machining CO_2 laser cutting is introduced. CO_2 laser cutting machine was first produced in 1970s and it is first in the world. Now, after over 30 years, CO_2 laser cutting machine has been improved in order to meet the constant expansion of its application fields. Today's market demand in laser cutting production, especially in 2D plate cutting and 3D spatial curve cutting is very high as it also gets attention from international and domestic companies. According to the Year 2000 Annual report statistics of "Industrial Laser Solution" an authoritative magazine in American laser industry: in 1999, the total sales of laser cutting system all over the world is mainly CO_2 laser cutting system is 3325, totalling to $1.174 billion (Anonymous, 2019).

Traditional cutting process such as plasma cutting, gas cutting, mechanical cutting and others also have some drawbacks. The benefits of laser cutting technology have shielded the weaknesses of traditional machining. Laser cutting is able to perform faster than mechanical cutting. The ability of laser cutting to cut complex profile makes it a suitable choice for high production. Besides that, the low temperature or low heat affected zone (HAZ) of laser also makes it reasonable to cut the low temperature material such as plastic and wood. One of the principles of laser cutting is its non-mechanical contact, which means there is no physical contact between laser and workpiece. This makes laser cutting to be capable in machining brittle material compare to traditional cutting as it save the risk of material cracked. A high quality end product of laser cutting reduces the secondary process of machining. However, it has some inherent limitations such as low energy efficiency and difficulties in processing circular engineering components.

A mechanical lathe is used to fashion stock material into specific tabular geometries and one of them is groove shape. When talking about groove, the depth and width should always be the concern. Therefore, the demand of groove size that is less than 0.3 mm is difficult to be achieved by a mechanical lathe and this requires an alternative manufacturing technologies. The proposed laser groove technology is expected to fill this gap when it comes to groove machining of high precision parts with fine tolerances for both metallic and non-metallic stocks. Accuracy and tolerance are very important especially in the medical industry which deals with critical components. The main intention of this research work is to engineer the mechanism and adopt a new stock grooving potential on an existing flatbed laser cutting machine.

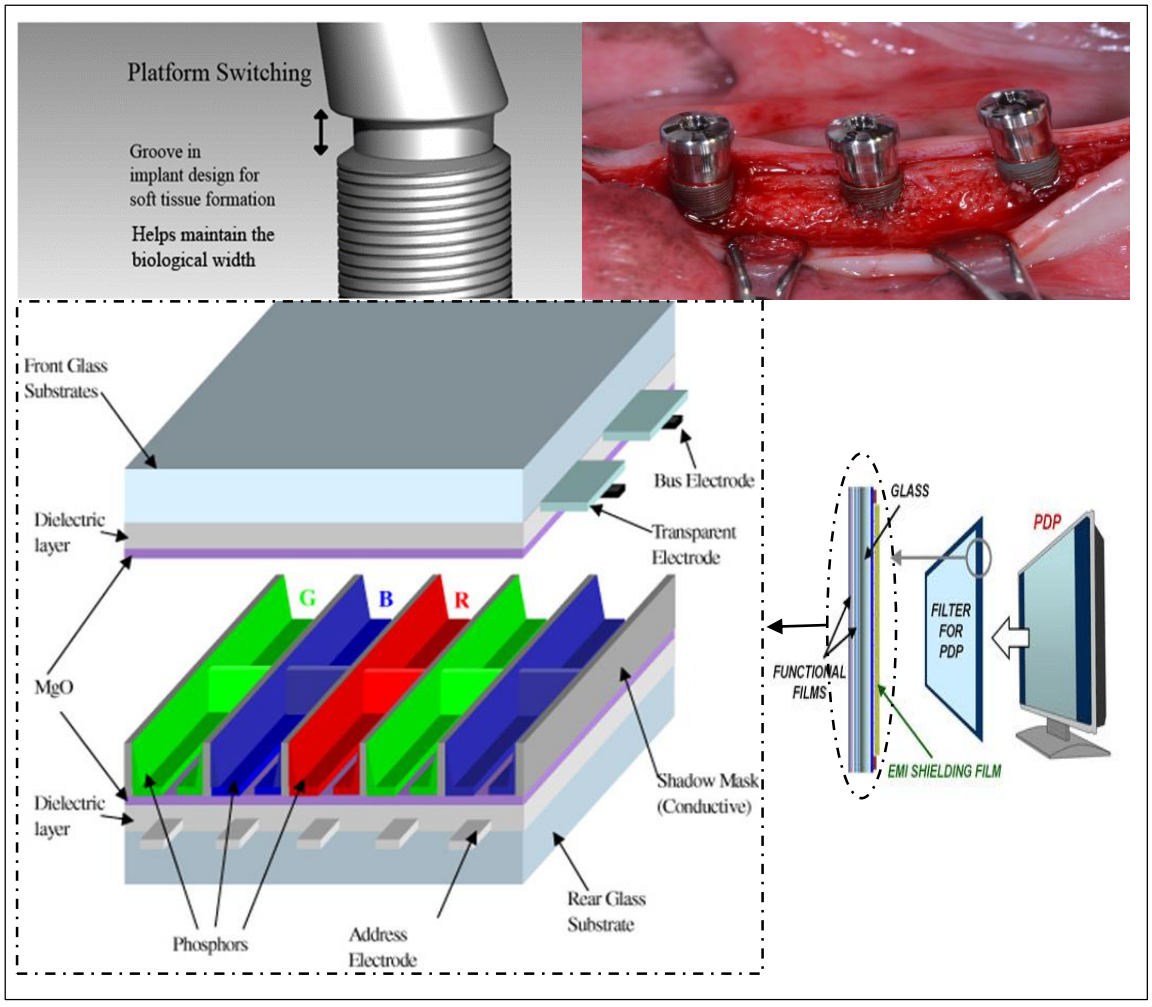

Figure 1.1: Micro-groove application on biomedical and electronic device

1.2 Problem statement

The development of technology, especially manufacturing technology is always changed by current development. Thus, the costs of manufacturing industry is becoming higher and higher because of changes in technology. Among factors that contribute towards an increase in cost of industries are facilities and equipment (Star, 2017). With the advancement of design, it require advanced machine that suits current technology. By the way, the academic institutions also face the same problem and it is unfair for academic institution to spend a lot of money just for new development of machine technology. Therefore, industries and academic institutions need to be more creative and innovative in line with current technology.

Thus, laser groove technology is proposed to be done on the existing flatbed laser cutting machine which has been designed to only cut flat stock. Although laser lathe existed in market, the cost is very expensive and complex. Therefore, an alternative mechanism is designed to convert 2D into 3D cutting. The conversion of existing flatbed laser cutting machine specifies that the function of laser cutting are the same with mechanical lathe. In term of cost effective, machining using laser cutting is with much lower cost compared to machining using mechanical lathe as laser has no used of cutting tool.

Besides that, material to be cut by mechanical lathe depends on cutting tool and to cut material especially 5 mm diameter of pure titanium grade 2 is almost impossible. Compared to laser cutting, there is no cutting tool used and it is means as a non-contact machining, so there is no risk of material deflection. Groove plays an important role particularly for seal mechanism. Therefore, the depth and width of groove are the crucial part to produce especially for micro level. A special technology such as laser cutting machine is viewed as an alternative technology to produce micro-groove. Thus, based on above statement it is bring out some research question of this study such as how to transform CO_2