RESPONSE SURFACE MODEL (RSM) OF CO_2 LASER CUTTING

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This report is submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Manufacturing Process) (Hons.)

by

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Manufacturing Process) (Hons). The member of the supervisory committee are as follow:

……………………..................................

(Prof. Dr. Ir. Sivarao A/L Subramonian)

ABSTRAK

Kaedah pemotongan material menggunakan pemotongan laser mempunyai kelebihan tersendiri dan penggunaannya kini semakin meluas terutamanya dalam sektor pembuatan. Dalam projek ini, kajian dibuat ke atas keluli dengan ketebalan 6 mm. Kajian dilakukan untuk mengetahui pengaruh parameter mesin terhadap kualiti pemotongan iaitu dari segi 'surface roughness' dan 'kerf width'. Dalam kajian ini kaedah 'Design of Experiment' digunakan iaitu 'Response Surface Model', RSM. Experiment dijalankan dan kemudian analisis dilakukan. Tiga parameter digunakan dalam kajian ini iaitu, kelajuan pemotongan (cutting speed), kekerapan(frequency) dan juga pusingan tugas (duty cycle). Didapati, kelajuan pemotongan dan pusingan tugas mempunyai kesan yang besar ke atas hasil potongan. Dalam pada itu, kekerapan juga mempengaruhi hasil potongan iaitu apabila berinteraksi dengan parameter lain. Didapati 'surface roughness' terbaik yang diperolehi ialah 2.61 μm manakala untuk 'kerf width' pula ialah 0.392 mm. hasil ini diperolehi apabila kelajuan pemotongan ditetapkan pada kelajuan 1200 mm/min manakala kekerapan di tetapkan pada 1800 Hz. Dalam projek ini, formula matematik untuk pemotongan laser dihasilkan. Formula yang berbeza dihasilkan iaitu menggunakan kaedah 'Response Surface Model'. Formula matematik ini kemudian diuji ketepatannya dengan melakukan sekali lagi eksperimen.

ABSTRACT

Laser cutting has great ability in cutting material and the use of laser cutting become widely in manufacturing field. In this paper, experimental investigation into 6 mm thickness of mild steel has been carried out. Influence of laser cutting machine parameters on 6 mm thickness mild steel in term of surface roughness and kerf width will be experimentally investigated. There are so many ways to optimize the parameter in laser cutting such as Taguchi, Full Factorial design, and Response Surface Model (RSM). Among these design of experiment, previous research has shown that Response Surface Model (RSM) is more critical and accurate compared to others. Thus, Response Surface Model (RSM) has been applied in this study to minimize the number of experiment, and selecting the optimal conditions of parameter. Response surface methodology based optimal parametric analysis has been performed to determine the optimal setting of process parameters which are cutting speed, frequency and duty cycle to achieved minimum kerf width and surface roughness. Cutting speed and duty cycle has significant effect to the response, however in interaction frequency shows it significant effect. Minimum surface roughness and kerf width has been obtained as 2.61 μm and 0.393 mm. When the cutting speed and frequency are set at optimal parametric setting i.e. 1200 mm/min and 1800 Hz. The mathematical model has been established based on regression analysis by response surface model.

DEDICATION

Only
my beloved father, Mohamed Ayub Khan
my appreciated mother, Roszalmi
my adored sister, Qistina
for giving me moral support, money, cooperation, encouragement and also understandings
Thank You So Much & Love You All Forever

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LIST OF ABBREVIATIONS, SYMBOLS, SPECIALIZED NOMENCLATURE

ANOVA	-	Analysis of Variance
BBD	-	Box-Behnken Design
CCD	-	Central Composite Design
CCRD	-	Central Composite Rotation Design
DO	-	Dissolved Oxygen
DOE	-	Design of Experiment
DPSSL	-	Diode Pumped Solid-State Laser System
EDM	-	Electrical Discharge Machining
FE	-	Fenite Element
GA	-	Genetic Algorithm
MMCs	-	Metal Matrix Composites
MOE	-	Modulus of Elasticity
MOR	-	Modulus of Rupture
MRR	-	Material Removal Rate
OA	-	Orthogonal Array
PMEDM	-	Powder Mixed Electrical Discharge Machining
Ra	-	Surface Roughness
TWR	-	Tool Wear Rate
WEDM	-	Wire Electrical Discharge Machining

CHAPTER 1

INTRODUCTION

In this chapter, a detailed introduction of this study have been explained. There will be brief explanations on project background and problem statement to solve. The objective of this study also have been stated clearly. Other than that, this part of project will point out the scope that the project will cover and significance of this project.

1.1 Project Background

The approach of selecting the suitable and most optimal conditions for the machining have been studied over the last few decades. The conditions of machining during cutting process such as feed rate, depth of cut and cutting speed need to be optimize in terms of economics machining operations, assessed by productivity and total manufacturing cost per component or some other suitable criterion.

Nowadays, the selection of cutting process parameter are made by operator or technician who handled the machine. However, to obtain optimum conditions even handled by an experienced and skilled operator might be difficult. Thus, this research will help to find the optimal parameter of machining process by using Design of Experiment (DoE) analysis.

The experiment will be focused on the interaction between variables to evaluate high performance responses of the machining process. The analysis is run by using the Design Expert 8 P (DX8P) software. Response Surface Methodology and factorial design models will be compared in terms of their modelling capabilities.

1.2 Problem Statement

Metal and aluminum machining have been used in industry since 18th century. Metal machining has widely used in manufacturing industry ever since the industrial revolution. In continuity of controlling the machining parameters during the process become critical and important. The needs of optimization are crucial in terms of providing high precision and efficiencies of machining. It is also minimize the process of machining time and cutting force, improve productivity and tool life and obtain better quality of producing product.

There are too many parameters that need to control in metal machining and it is very difficult to identify which are the most affected parameters. This has leads to time wasting and cost for metal machining activities. Metal machining efficiency cannot be achieved if the parameters that contribute to maximum effect of the product cannot be recognized. To control many parameters during machining process will leads to complicated process and finally the quality of the product will not meet the requirement.

1.3 Objectives

The DoE method has been used widely not only in manufacturing industry but also in a food industry, and aerospace industry. It is been recognized that DoE method as an effective method to control the relationship between input parameters and the output variable. Thus, the objectives of this research are listed below.

1. To identify the significant parameters in metal machining
2. To investigate the interaction between the optimal parameters
3. To establish the prediction model for response identification

1.4 Scope of the Project

The purpose of this research is to design an experiment in order to determine the significant parameters for the metal machining. Helius hybrid laser cutting is the machine that has been chosen to undergo this experiment. The material to be used for this experiment is mild steel with 6 mm thickness. Once the significant parameters been identified, the process of selecting the optimization of the significant parameter will take place. The analysis will cover on interaction between the parameter to determine whether the parameter has direct or indirect interaction. Based on the analysis, the model or equation will be established. For this project, a software that will be used to analyze the data is Design Expert 8 P (DX8P) software. The parameters on the laser cutting machine will be analyze by using the software based on DoE method. Response Surface Model (RSM) will be used to compare the differences of the design. Finally, the mathematical model will be derived in order to determine the most effected parameter to the product quality.

1.5 Project Significance

This research study will contribute to improve the efficiency in metal machining by controlling a significant parameter which can be optimized to the maximum. The importance of the study is as follows:

a) To make an essential approach of the parameter by using Design of Experiment (DoE).
b) To provide the optimal conditions in metal machining especially laser cutting.
c) Optimal machining by means high precision and efficiency of the machine which can minimize the machining time, reduce scrap and eliminate complicated process.

CHAPTER 2

LITERATURE REVIEW

This chapter is the summary of the related topic that have been carried out by other researchers. The discussion about Design of Experiment (DoE) information was gained from the journals, books and internets. A brief explanation regarding the laser cutting and specification of the machine is being discussed in this chapter. The application of DoE using different design of experiment which is Response Surface Method (RSM) has been summaries in this chapter in order to select the optimal conditions of parameter.

2.1 Laser Cutting Overview

Laser cutting is one of the non-contact type thermal process and well-known process in the metal industry. It is undeniably that laser cutting have high precision, high product quality, adequacy to multiple, low level of noise, flexibility, ease of automation, and very low waste production, W.M. Steen (2010). This laser cutting process have a few different types of process which consists of drilling, cutting and milling. Laser machining also includes subcategories of laser grooving, and engraving. In terms of parameter, there are two types of parameter in laser cutting which is discussed below.

2.1.1 Non-controllable laser parameters

Non-controllable parameters refer to parameters which depends on initial equipment system or selected material for cutting process. Below are the three types of non-controllable parameters consisting of surface roughness of material, pulse-repetition rate and pulse width/energy per pulse.

i. Surface roughness of material

Surface roughness is an obvious factor affecting reflectivity. Rough surface tends to create multiple reflections and gives the surface more chances to absorb more laser beam and thus reduce the reflectivity and increase the absorption.

ii. Pulse repetition rate

This parameter is more to laser drilling process or making hole by using laser. Pulse repetition rate is the number of discharge pulses influencing on how a quality holes is created at a certain rate of time by drilling process.

iii. Pulse width/energy per pulse

The pulse energy setting is depends on material thickness, composition and hole diameter. At higher pulse energy, cutting rate is increased and drilling time is reduced. Increasing the pulse width at fixed peak power on the other hand effectively increase the energy per pulse of laser.

2.1.2 Controllable laser parameters

Controllable parameter can be described that, parameter which can be modified or adjusted on the laser machine before cutting process is conducted. They consist of cutting speed, laser power, gas pressure, gas jet selection, continuous wave (CW), gated pulse (GP), nozzle types, focus lens type, focal distance (FD), stand-off distance (SOD), nozzle diameter, beam diameter, federate, frequency and duty cycle (DC). Each parameter from 14 that listed, setting leads to different cutting method, time effect and effectiveness as well as the quality.

Setting of a single parameter might eliminate another aspect of problem but at the same time, it could also cause another feedback which may affect in another parameter set. For an example, the relationship between laser power and speed is complicated even though laser has high-powered that capable to cut at faster speed and resulting high productivity. Unfortunately, high-powered laser tend to have a focusing problem which leads to larger focused spot and cut widths. The need to remove more material to produce the cut are actually slowing the process to some extent. Besides that, poor beam quality produce from high-powered laser makes them more suitable for heat treating and welding rather than cutting.

i. Cutting speed

One of the most important controllable parameter is a cutting speed because it influencing edge quality of a cut. As the thickness of material increase, the cutting speed required in maintaining cutting quality is decreases. Nitrogen-assisted cutting is a slower process that produces higher quality product. The cutting speed by using this gas jet is generally 30-60% of the oxygen-assisted cutting speed. The cutting speed such as the laser output must be convenient to the types of material and material thickness. An error in cutting speed can affect the roughness, burr formation or pits in the cut contour. If the contour cut too quickly, the material could not be separated at all.

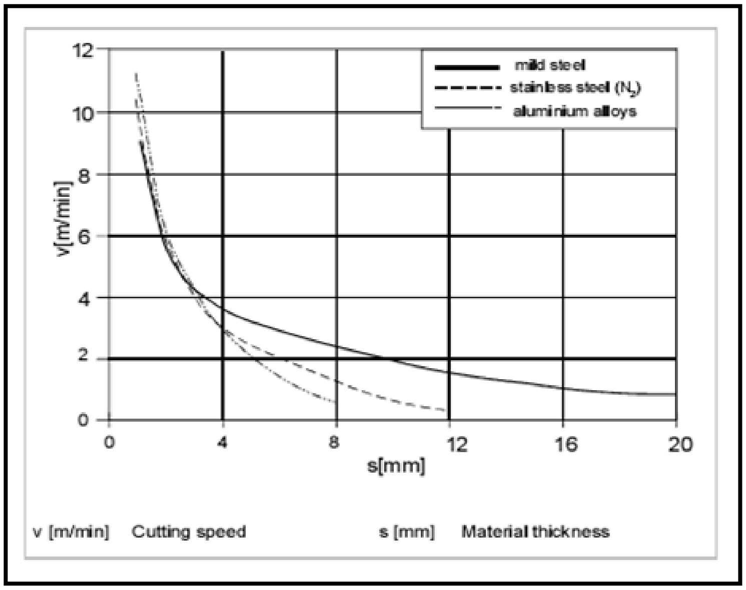

Figure 2.1: Maximum Cutting Speed with 4000 W Laser Output as Affected by Material Thickness. (TRUMPF, 2000)

In general, the cutting speed must be reduced with increasing material thickness. Figure 1.3 illustrates the maximum cutting speed with 4000 W laser output as affected by material thickness. Nitrogen assisted cutting is a slower process but however that produces a higher quality product. The cutting speed by using this gas jet is generally 30% to 60% of oxygen assisted cutting speed.

ii. Gas pressure

Gas pressure refers to the assist gas pressure and it is measured at the conditions where it comes out from nozzle orifice. The cutting gas pressure and size of the nozzle are influencing the gas consumption. The cutting speed can be increased by the increasing the gas pressure but it may damage the surface roughness Thus, this is needed to be carefully controlled so that an optimal quality cut is provided. Figure 1.4 and Figure 1.5 illustrates the cutting with oxygen with a cutting gas pressure up to 6 bars and cutting with nitrogen with a cutting gas pressure up to 20 bars. For Figure 1.7 shows that, as the gas volume per time increases, the pressure decreases for the largest size of nozzle orifice of the cutting with oxygen. Figure 1.26 indicates, for the largest size of nozzle orifice of cutting in nitrogen, the pressure in bar increases with the increasing of gas volume per time.

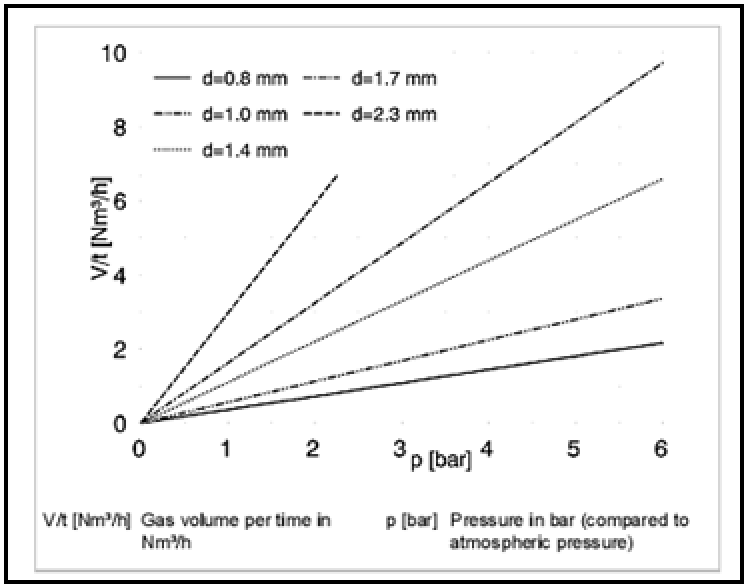

Figure 2.2: Maximum Cutting Gas Consumption per Hour in Continuous Cutting for Cutting with Oxygen with Gas Pressure Up to 6 Bars. (TRUMPF, 2000)

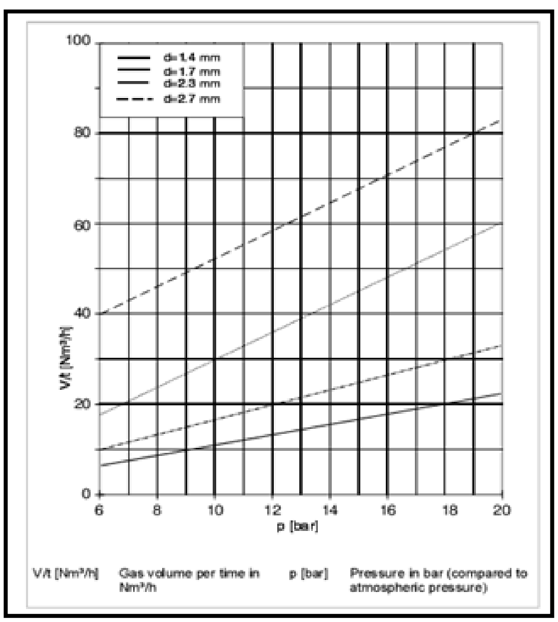

Figure 2.3: Maximum Cutting Gas Consumption per Hour in Continuous Cutting with Nitrogen with Gas Pressure Up to 20 Bars. (TRUMPF, 2000)