OPTIMIZATION OF CARBON DIOXIDE LASER CUTTING PARAMETERS

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ABSTRACT

This thesis presents the study of multi-optimization of carbon dioxide laser cutting process. There are many types of parameters involved in laser cutting which can be optimized in order to get the best quality output. In this study, three parameters are selected which are cutting speed, laser power frequency and its standoff distance to the workpiece. This thesis described how different sets of parameters can affect the result of laser cutting generated. The material chosen for this experiment is cast acrylic plastic glass. The range for cutting speed is 30*mm/min*, 40*mm/min* and 50*mm/min*. As for laser frequency variable, the levels are between 5 *kHz*, 10 *kHz* and 15 *kHz* while a set of 30*mm*, 60*mm* and 90*mm* are chosen for the standoff distance parameter. The theories show that higher value of each variable will generate smaller kerf width mark. From the analysis, it was found that the standoff distance proved to be the most significant influence to the result of kerf width produce.

ABSTRAK

Tesis ini membentangkan kajian pengoptimuman pelbagai parameter untuk proses pemotongan laser berasaskan karbon dioksida. Terdapat banyak jenis parameter yang terlibat dalam proses pemotongan laser. Semua parameter ini boleh dioptimumkan untuk mendapatkan kualiti hasil yang terbaik. Dalam kajian ini, tiga parameter dipilih yang kelajuan pemotongan, frekuensi dan jarak antara laser dan bahan kerja. Tesis ini menggambarkan bagaimana set parameter yangberlainan boleh mempengaruhi hasil pemotongan laser. Bahan yangdipilh untuk eksperimen ini adalah kaca akrilik plastik. Setiap parameter telah ditetapkan kepada tiga peringkat julat nilai untuk mewujudkan kepelbagaian set eksperimen. Julat bagi kelajuan pemotongan 30*mm/min*, 40*mm/min* dan 50*mm/min*. Bagi pemboleh ubah frekuensi laser, paras antara 5*kHz*, 10 *kHz* dan 15 *kHz* manakala satu set 30*mm*, 60*mm* dan 90*mm* dipilih untuk parameter jarak antara laser dan bahan eksperimen. Teori menunjukkan bahawa nilai yang lebih tinggi bagi setiap pemboleh ubah akan menjana lebih kecil jurang ruangan hasil pemotongan laser. Berdasarkan keputusan yang dihasilkan, ia mendapati bahawa parameter jarak antara laser dan bahan eksperimen terbukti menjadi pengaruh yang paling ketara kepada jurang hasil pemotongan laser.

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LIST OF SYMBOLS

mm/min	Millimeter per minute
kHz	Kilohertz
mm	Millimeter
nm	Nanometer
μm	Micrometer

LIST OF ABBREVIATIONS

Laser	Light Amplification by Stimulated Emission of Radiation
CO_2	Carbon Dioxide
GA	Genetic Algorithm
PSO	Particle Swamp Optimization
EP	Evolutionary Programming
OA	Orthogonal Array
S/N	Signal to Noise
DOE	Design of Experiment
ANOVA	Analysis of Variance

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Laser cutting is one of the applications that regarded importantly in manufacturing industry. Yilbas et al. (2008) found that laser cutting of engineering metals finds applications in industry due to rapid processing, precision of operation and achievement of good end product quality. It is mainly used for sheet metal cutting. It is believed that approximately 12 000 industrial laser cutting systems have been installed world-wide with a total market value over 5 billion USD. (Shirley, S. 2009)

Laser cutting is more high quality than other conventional in term of flexible and much more cost effective. Lasers are capable of cutting steel, stainless steel, super alloys, copper, aluminum, and a variety of other metals and alloys. They can also cut non-metallic materials such as ceramic, quartz, plastic, thermoplastic, rubber, wood and a whole lot more. Laser cut quality cannot be easily predicted. This is due to the dynamic nature of the laser cutting process, and it is particularly obvious when cutting ferrous alloys using oxygen as an assisting gas. (Yi, Z. 2009)

1.2 PROBLEM STATEMENT

This study makes a research in using selected optimization method as the design of experiment to find the optimum values of laser cutting parameters. The trial and error method is not reliable enough to sort out the best cutting quality. Hence, a proper optimization method is used to solve finding out the optimum laser cutting parameter.

1.3 PROJECT BACKGROUND

Many studies have been done on laser cutting processes which indicate the wide usage of laser cutting applications in various fields. Each sector is looking out for efficient ways of improving their productivity by researching far more efficient process. Laser cutting process is one of the examples of latest technology inventions that offer that kind of advantages.

According to Cresci, A et al. (2009), laser cutting acrylic requires minimal jigging and fixturing making it an ideal process for cutting pieces that are difficult to hold using mechanical cutting methods. Lasers are quick to set-up and so smaller production runs and one-off pieces are more practical to produce using laser cutting. Cutting lasers have no mechanical tools that wear during production. As such the finished product is highly accurate, with extremely high repeatability of detail.

In contrast, mechanical cutting leaves a rougher edge finish to the cut surface than laser cutting, which need additional operations to achieve the standard of finish achieved with a laser (Mendes, J. A. 2003). Laser cutting acrylic leaves a polished, finished edge requiring no further work. In some instances it is not possible to access the cut edge fully enough to polish and so the acrylic has to be laser cut.

However, the output would still very much depend on parameters setting. Different inputs of variables is definitely going to affect the cutting quality. Thus, this project is created to select possible variables of laser cutting process to optimize and find the most significant variable that need to be taken as the main priority among the others due to its highest influence to the cutting quality produced on the material. (Tsai, M et al. 2007)

1.4 RESEARCH OBJECTIVES

The objectives of the study are:

i. To study the optimum CO_2 laser cutting parameters
ii. To study the effects of the parameters on kerf width
iii. Analyze the data collected from the experiment done

1.5 PROJECT SCOPES

The project scopes of the study are:

i. Using different sets of each parameters ; cutting speed, focal length and standoff distance of nozzle, laser power range during operation and study the outcomes
ii. Run the experiment using laser cutting machine

1.6 THESIS ORGANIZATION

The content of this thesis will be divided into five main chapters and all data will be organized according to chapters. Those will represents the flow of contents inside the thesis report.

For Chapter 1, this will be the opening chapter that explains and elaborates the main talking point of the thesis project including title, objectives, problems statement, project scopes and the context flow. Chapter 2 meanwhile explains more towards the meanings and all the background information needed regarding to the project. This means that data from previous researches or various sources are used as references to this project. All these data can help simplify the concept understandings and enlighten the flow of the project itself. This chapter will largely conclude more about the laser fundamentals and principles.

In Chapter 3, it is about the methodology of the project. All apparatus and methods used in this research will be listed here. Chapter 4 presents all the results produced from the experiments. This chapter will be the findings and analysis section of the project. The data will be compared to the previous data. Then, determine whether the results help in improving the efficiency of the carbon dioxide laser cutting machine performance.

Chapter 5 clarifies the summary of the research done and states if the objectives are achieved. This section also can be informed of any kind of extra findings that are found during the project. Those will help in giving new information for further research of the field in the future. Suggestions also are listed in improving the flow of the next experiment so that a more accurate result can be gained.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter includes all types of information that related to the study. Through this chapter, there are lots of explanations and details about basic knowledge of laser, laser fundamentals, laser cutting and variety of optimization methods. It is important to gain all the information as much as possible to help getting a clear view of what this project is all about.

Collecting all sorts of sources related to the laser will help in establishing a theoretical framework for the project thus making sure the project is run with full of preparations. It involves studying and defining key terms, definitions and all types of terminologies included in this research.

2.2 LASER

According to Aldrich (2001), the word "laser" is an acronym for Light Amplification by Stimulated Emission of Radiation. Lasers are finding ever increasing military applications principally for target acquisition, fire control, and training. These lasers are termed rangefinders, target designators, and direct-fire simulators. Lasers are also being used in communications, laser radars (LIDAR), landing systems, laser pointers, guidance systems, scanners, metal working, photography, holography, and medicine. Figure 1 illustrates the total electromagnetic spectrum and wavelengths of the various regions (Aldrich, R. 2001).

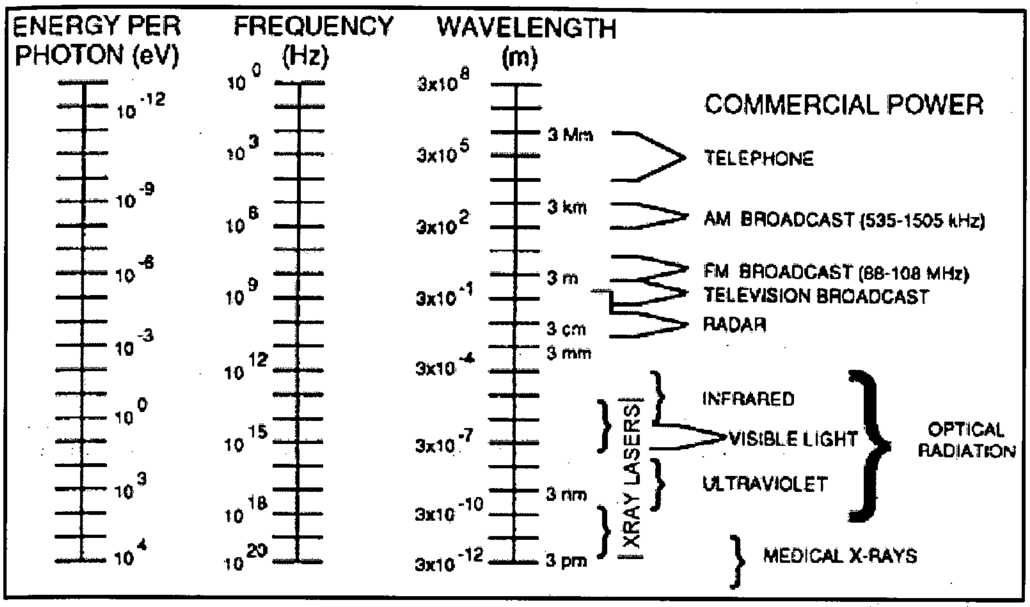

Figure 2.1 Electromagnetic Spectrum (Aldrich, R.2001)

According to Aldrich, R. (2001), the primary wavelengths of laser radiation for current military and commercial applications include the ultraviolet, visible, and infrared regions of the spectrum. Ultraviolet radiation for lasers consists of wavelengths between 180 and 400 *nm*. The visible region consists of radiation with wavelengths between 400 and 700 *nm*. This is the portion we call visible light. The infrared region of the spectrum consists of radiation with wavelengths between 700 *nm* and 1 *mm*. Laser radiation absorbed by the skin penetrates only a few layers. In the eye, visible and near infrared radiation passes through the cornea, and is focused on and absorbed by the retina. It is the wavelength of the light that determines the visible sensation of color: violet at 400 *nm*, red at 700 *nm*, and the other colors of the visible spectrum in between (Aldrich, R. 2001) . When radiation is absorbed, the effect on the absorbing biological tissue is either photochemical, thermal, or mechanical: in the ultraviolet region, the action is primarily photochemical; in the infrared region, the action is primarily thermal; and in the visible region, both effects are present. When the intensity of the radiation is sufficiently high, damage to the absorbing tissue will result.

Lasers work as a result of resonant effects. The output of a laser is a coherent electromagnetic field. In a coherent beam of electromagnetic energy, all the waves have the same frequency and phase. Figure 2.1 below shows the basic diagram of laser mechanism.

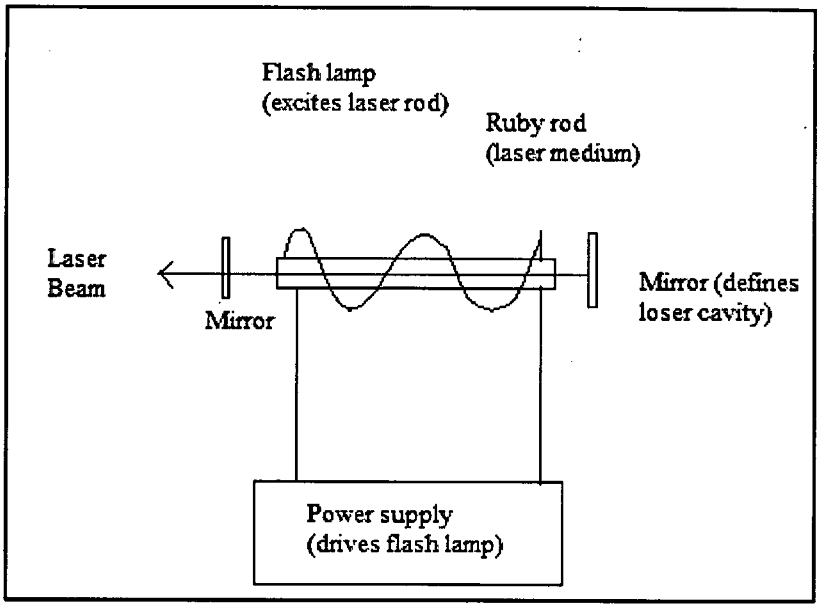

Figure 2.2 Basic Diagram of Laser Mechanism (Hänsch. 2002)

Ghatak & Thyagarajan (2010) stated that the light emitted by ordinary sources of light, like incandescent lamp, is spread over all directions and is usually over a large range of wavelengths. In contrast, the light from a laser could be highly monochromatic and highly directional. According to Silfvast, W. T. (2004), laser generally have a narrower frequency distribution, or much higher intensity, or a much greater degree of collimation, or much shorter pulse duration, than that available from more common types of light sources. Thus, in its simplest form, a laser consists of a gain or amplifying medium where stimulated emission occurs and a set of mirrors to feed the light back into the amplifier medium for continued growth of the developing beam.

2.3 LASER CUTTING

Laser cutting is a fast, non-contact method for cutting or slitting a wide range of metal and non-metal materials. Unlike most other processes, laser cutting does not suffer from tool wear which eliminates a myriad of part tolerance and maintenance issues. (Yilbas, et al. 1998)

Yilbas, et al. (1998) stated that laser cutting does not require any hard tooling as does a punch press or shear, it is a very "lean" manufacturing method eliminating the need for tool changeover, tool storage and tool sharpening maintenance. Laser cutting does not suffer from electrode wear from each hole drilled in the workpiece

When compared to other thermal cutting processes such as plasma or flame cutting, laser cutting utilizes a much more focused spot, or smaller cutting tool, so it puts much less heat into the workpiece and removes a narrower path of material. It was found by Shirley, S. (2008) that this allows the laser to cut more precise parts to a higher tolerance and with less taper on the cut edge.

In carbon dioxide laser, unlike atomic lasers, CO_2 lasers work with molecular transitions (vibrational and rotational states) which lie at low enough energy levels that they can be populated thermally, and an increase in the gas temperature, caused by the discharge, will cause a decrease in the inversion level, reducing output power (Griot, M. 2005).

To counter this effect, high-power CO_2 lasers use flowing gas technology to remove hot gas from the discharge region and replace it with cooled (or cooler) gas. With pulsed CO_2 lasers that use transverse excitation, the problem is even more severe, because, until the heated gas between the electrodes is cooled, a new discharge pulse cannot form properly. (Griot, M. 2005)

There are so many advantages can be found in laser cutting application that makes it preferable to manifacturers. One of the its common advantages is fast setup time for material preparation before proceeding with the operation as in involves no tooling which reduces ineffective time tool changeover. Another advantage is the ability to produce narrow cut kerf of the material which shows a better quality of proccess. This also shows the efficient details in accuracy when doing the cutting operation. Morevover, the laser cutting process have less heat input to the process which at the same time helps reducing thermal damage to the material. Less tooling in this process have proven to keep the operational cost to the minimum level.

2.4 OPTIMIZATION METHODS

In optimizing the parameters, there are variety types of optimization methods in order to get the optimal result for each parameter. It is are important that the optimization techniques used with coercion provide opportunities for the optimizer to converge on a value needed for transformation or provide an increase in insight about the simulation. The two elements that most directly affect the success of an optimization technique are the quantity and domain of decision variables and the objective function. (Marler, R. T. & Arora, J. S. 2004)

According to Mohsine & Hami (2009), the search in reliability-based design optimization is becoming an important engineering design activity. Traditionally for these problems, the objective function is to minimize a cost function while satisfying the reliability constraints. The reliability constraints are usually formulated as constraints on the probability of failure. This has led to the introduction of variety optimization methods including mathematical methods, iterative approaches, artificial intelligence tools, and hybrid techniques (Farhat & El-Hawary, 2009). Over the years, different methodologies have been applied. Decision variables are parameters to a simulation that are deemed to affect the output in a significant manner.

Selecting the best set of decision variables can sometimes be a challenge because it is difficult to ascertain which variables affect each specific behavior in a simulation. Logic determining control flow can also be classified as a decision variable. Condition statements, for example, can be optimized to produce a transformation or to gain insight about the simulation just as variables within the simulation can. The domain of potential values for decision variables are typically restricted by constraints set by the user.

2.4.1 GENETIC ALGORITHM

Genetic algorithm (GA) is a random method which simulates some laws of nature to solve large-scale combinatorial optimization problems. It abandons the traditional search methods, simulates the natural process of biological evolution, uses artificial evolution methods to conduct random searches on the target space. With robust, global optimality, independent of the properties of the problem model, and parallel and high-efficiency, GA is more and more widely used in various fields with a unique appeal. (Zhao, T. & Wang, X. 2010)

According to Ekart et al. (2003), one of the important technical terms in GA is *chromosome*, which is usually a string of symbols or numbers. A chromosome is a coding of a solution of an optimization problem, not necessarily the solution itself. GA starts with an initial set of randomly generated chromosomes called a *population*. The number of individuals in the population is a predetermined integer and is called *population size*. All chromosomes are evaluated by the so-called *evaluation function*, which is some measure of *fitness*.

Meanwhile, Bogart et al. (1990) stated that genetic algorithms are a robust adaptive optimization method based on biological principles. A population of strings representing possible problem solutions is maintained. Search proceeds by recombining strings in the population. The theoretical foundations of genetic algorithms are based on the notion that selective reproduction and recombination of binary strings changes the sampling rate of hyperplanes in the search space so as to reflect the average fitness of strings that reside in any particular hyperplane. Thus, genetic algorithms need not search along the contours of the function being optimized and tend not to become trapped in local minima.

2.4.2 PARTICLE SWAMP OPTIMIZATION

According to Schutte (2008), Particle Swarm Optimization (PSO) is an approach to problems whose solutions can be represented as a point in an n-dimensional solution space. A number of *particles* are randomly set into motion through this space. At each iteration, they observe the "fitness" of themselves and their neighbors and "emulate" successful neighbors (those whose current position represents a better solution to the problem than theirs) by moving towards them.

PSO is introduced by Kennedy & Eberhart 1995 which are inspired by social behavior and movement dynamics of insects, birds and fish. Furthermore, PSO laso is a global gradient-less stochastic search method that suited to continuous variable problems. The performance of PSO comparable to Genetic algorithms which is the reason why it has successfully been applied to a wide variety of problems (Kavuslu, M. A. 2011)

Various schemes for grouping particles into competing, semi-independent *flocks* can be used, or all the particles can belong to a single global flock. This extremely simple approach has been surprisingly effective across a variety of problem domains. The choice of PSO parameters can have a large impact on optimization performance. Selecting PSO parameters that yield good performance has therefore been the subject of much research. (Qiang, F. et al 2009)

PSO has its own advantages and disadvantages. For advantages, PSO is insensitive to scaling of design variables but has simple implementation which makes it easily parallelized for concurrent processing. It is also derivative free and has very few algorithm parameters yet very efficient global search algorithm. On the other hand, PSO is known to its slow convergence in refined search stage (weak local search ability). (Schutte, J. F. 2005)

2.4.3 EVOLUTIONARY PROGRAMMING

Evolutionary Programming (EP) is a subset of evolutionary computation, a generic population-based metaheuristic optimization algorithm. EP is a useful method of optimization when other techniques such as gradient descent or direct, analytical discovery are not possible. The objective of the Evolutionary Programming algorithm is to maximize the suitability of a collection of candidate solutions in the context of an objective function from the domain. (Bueller, S. 2005)

Evolutionary Programming was developed by Fogel and refers to that class of methods in evolutionary computation that apply a (uniform) random mutation to each member of a population, generating a single offspring. However, unlike other methods, no recombination operators are applied. Population members may be considered as representative of species, rather than individuals, so phenotypic effects are emphasized instead of genetic change. After mutation, selection takes place, and half the combined population of parents and offspring enter the next generation. Such methods are generally simple, robust and highly parallel. Underused for many years, they were further developed in the 1980s and their use became more widespread in single-objective optimization. However, they remain underused in multi-objectives optimization. (Lewis, A. & Abramson, D. 2007)

2.4.4 TAGUCHI METHOD

Taguchi methods is a statistical method developed by Genichi Taguchi to improve the quality of manufactured goods, and more recently also applied to engineering, biotechnology, marketing and advertising. Professional statisticians have welcomed the goals and improvements brought about by Taguchi methods, particularly by Taguchi's development of designs for studying variation, but have criticized the inefficiency of some of Taguchi's proposals. (Ramasamy, M. 2007)

Dr. Taguchi of Nippon Telephones and Telegraph Company, Japan has developed a method based on "Orthogonal Array" experiments which gives much reduced "variance" for the experiment with "optimum settings "of control parameters. Thus the marriage of Design of Experiments with optimization of control parameters to obtain BEST results is achieved in the Taguchi Method. "Orthogonal Arrays" (OA) provide a set of well balanced (minimum) experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results. (Ballantyne & Mitchell. 2007)

2.5 ACRYLIC PROPERTIES

The term "acrylic" is used for products that contain a substance derived from acrylic acid or a related compound. Most often, it is used to describe a clear, glass-like plastic known as poly(methyl) methacrylate (PMMA). PMMA, also called acrylic glass, has properties that make it a better choice for many products that might otherwise be made of glass. There are two basic types: extruded and cast. (Quek, K. Y. & Tam, S. C. 1991)

Extruded acrylic is made through a process in which the liquid plastic is pushed through rollers, which press it into sheets as it cools. This is a comparatively inexpensive process, but the resulting sheets are softer than cast acrylic, can scratch easier, and may contain impurities. Much extruded acrylic is still of very good quality, however, and it makes up the majority available in the market. It's a good choice for use in making signs, displays, and other uses. (Quek, K. Y. & Tam, S. C. 1991)

Cell cast acrylic tends of be of higher quality than extruded, but it's also more expensive. In cell casting, single sheets of acrylic are made by pressing the liquid plastic between pieces of a mold, often made of glass, which is then taken through a gradual heating process. The resulting sheet is stronger than extruded acrylic. This type is often used for aquariums, awards, and other products that require shaping or machining of the final product.

2.6 LASER CUTTING PARAMETERS

The laser cutting parameters are dependent on the beam characteristics, the cutting rate required, the composition and thickness of the material to be cut, and the desired cut edge quality. The laser cutting process and cut quality depend upon the proper selection of laser and workpiece parameters. Deficiencies in cutting quality may be related to the slow process drifts and disturbances that are caused by velocity fluctuations, variation in power and spatial intensity distribution as well as optical integrity perturbations.

According to Karatas et al. (2008), laser parameters such as laser output power and pulsating frequency, cutting speed, assisting gas pressure and focal distance determine the end product quality in laser cutting process. The sideways burning along the cutting paths results in poor cutting quality, particularly wedge cuttings in sheet metal forming. In order to improve the cutting quality for such situations, the laser parameters should be re-adjusted.

2.6.1 CUTTING SPEED

Higher cutting speeds give minimum cut deviation. This is because as the speed increases, less energy is absorbed by the material due to shorter interaction time which results in relatively low thermal stresses (Nisar et al., 2010) .The energy balance for the laser cutting process is such that the energy supplied to the cutting zone is divided into two parts namely; energy used in generating a cut and the energy losses from the cut zone. It is shown that the energy used in cutting is independent of the time taken to carry out the cut but the energy losses from the cut zone are proportion to the time taken.

Therefore, the energy lost from the cut zone decreases with increasing cutting speed resulting into an increase in the efficiency of the cutting process. A reduction in cutting speed when cutting thicker materials leads to an increase in the wasted energy and the process becomes less efficient. The levels of conductive loss, which is the most