OPTIMIZATION OF LASER CUTTING PARAMETER OF ACRYLIC BY USING DMAIC APPROACH

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To my beloved mother and father

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ABSTRACT

Laser cutting is the most common manufacturing process widely used nowadays and this is due to its flexibility, reliability, maximize material utilization by part nesting, time saving and low cost tooling. But, inappropriate control and setting may lead to material defects, machine malfunction or even catastrophe. Hence, the purpose of this study is to implement the ideas from lean six sigma for optimizing laser cutting conditions to prolong the service life of the laser cutting machine. The entire dissertation will be surrounded in optimize machining parameters for EPILOG Legend 36Ext – Model 9000 laser cutting machine in the FKM lab by using DMAIC approach. And, the whole idea of optimal control was encapsulated in Lean Six Sigma methodology which summarized in the abbreviation (DMAIC): Define, Measure, Analyze, Improve and Control. First of all, a list of problem statement has constructed to clarify the objectives of the project to be studied. Second, a value stream mapping diagram has constructed to serve as an overview of the entire maintenance management system in order to measure the bottlenecks between personnel and information flow from relevant management level. Third, a mathematical modelling software such as MATLAB was used to formulate the relationship between the cutting parameters towards the cutting quality of acrylic specimens. Forth, solutions to machining dysfunctions has proposed and optimum cutting conditions were developed by using Design Expert software. Fifth, a standard practice such as SOP (standard of procedure) was developed to replace current machining procedures. Finally, improved plans were further monitored in order to ensure the improvements were sustainable. After implementing DMAIC, it was found that the information given by supplier's manual should be continually revised since machining parameters due to deteriorate of machine parts. The values of revising SOP may help FKM lab to save cost in machine repair.

ABSTRAK

Laser memotong ialah proses pembuatan paling biasa digunakan secara meluas masa kini dan ini adalah disebabkan flexibiliti, kebolehpercayaan, memaksimumkan penggunaan bahan dengan nesting, menjimatkan masa dan kos peralatan. Tetapi, kawalan yang tidak sesuai dan persekitaran boleh menjurus kecacatan bahan, kepincangan tugas mesin malahan malapetaka. Maka, tujuan kajian ini adalah untuk melaksanakan idea bersandar enam sigma untuk mengoptimumkan keadaan pemotongan laser dan memanjangkan hidup perkhidmatan mesin pemotong laser. Seluruh disertasi akan dikelilingi dalam mengoptimumkan mesin parameter untuk EPILOG Legend 36Ext - Model 9000 mesin pemotong laser di makmal FKM dengan menggunakan pendekatan DMAIC. Dan, keseluruhan idea mengoptimumkan kawalan tersirat di Lean Six Sigma metodologi yang ringkaskan di singkatan (DMAIC): Takrif, Ukur, Analisa, Tambah Baik dan Kawal. Terlebih dahulu, satu senarai penyataan masalah telah dibina untuk menjelaskan objektif projek yang dikaji. Kedua, suatu gambar rajah pemetaan proses telah dibina untuk menjadi gambaran bagi keseluruhan sistem pengurusan penyenggaraan supaya mengukur percanggahan antara kakitangan dan aliran maklumat dari peringkat pengurusan berkaitan. Ketiga, perisian seperti MATLAB telah digunakan untuk membentuk hubungan antara parameter memotong dengan kualiti memotong spesimen-spesimen akrilik. Keempat, penyelesaian bagi disfungsi telah dicadangkan dan keadaan optimum telah dibina dengan menggunakan perisian Design Expert. Kelima, suatu amalan piawaian seperti SOP (standard prosedur) dibangunkan untuk menggantikan prosedur memesin semasa. Akhirnya, rancangan seterusnya dipantau supaya memastikan peningkatan secara mampan. Selepas melaksanakan DMAIC, ia telah didapati bahawa maklumat diberi oleh buku panduan pembekal seharusnya disemak secara berterusan kerana parameter dan bahagian mesin dijangka merosot dari semasa ke semasa. Manfaat menyemak SOP mungkin membantu makmal FKM menjimatkan kos dalam pembaikan mesin.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

5S	-	Sort, Straighten, Scrub, System, Standardize
ANOVA	-	Analysis of Variance
CMMS	-	Computer Managed Maintenance System
CO_2	-	Carbon Dioxide
CTQ	-	Critical to Quality
CW	-	Continuous Wave
DMADV	-	Define, Measure, Analyze, Design, Verify
DMAIC	-	Define, Measure, Analyze, Improve, Control
DMARC	-	Define, Measure, Analyze, Redesign, Control
DOC	-	Depth of Cut
DOE	-	Design of Experiment
DOWNTIME	-	Defect, Overproduction, Waiting, Non-utilized Talent, Transportation, Inventory, Motion, Extra-Processing
DPMO	-	Defects Per Million Opportunities
EAM	-	Enterprise Asset Management
FKM	-	Fakulti Kejuruteraan Mekanikal
FMEA	-	Failure Mode and Effect Analysis
FREQ	-	Frequency
GE	-	General Electric
HAZ	-	Heat Affected Zone
ISO	-	International Organization for Standardization
LHS	-	Left Hand Side
PRESS	-	Predicted Residual Sum of Squares
PW	-	Power
PWR	-	Power
Nd-YAG	-	Neodymium-doped Yttrium Aluminum Garnet (Nd: $Y_3Al_50_{12}$)
R^2	-	R Square

RCFA	-	Root Cause Failure Analysis
RCM	-	Reliable Centered Maintenance
RHS	-	Right Hand Side
RPN	-	Risk Priority Number
RSM	-	Response Surface Method
SEM	-	Scanning Electron Microscope
SIPOC	-	Supplier, Input, Process, Output, Customer
SOP	-	Standard of Procedure
SP	-	Speed
TPM	-	Total Productive Maintenance
TPS	-	Toyota Production System
TQM	-	Total Quality Maintenance
WCM	-	World Class Maintenance
XRD	-	X-Ray Diffraction

LIST OF SYMBOLS

α	-	Thermal Diffusivity
a	-	Absorbability Percentage
c_p	-	Specific Heat
D	-	Depth of Cut
exp	-	Exponential
f	-	Frequency
h	-	Material Thickness
k	-	Thermal Conductivity
$K_0(x)$	-	Modified Bessel Function of Second Kind of zero order
L_m	-	Latent heat of fusion per unit mass temperature
m_a	-	Mass
$\mathbb{N}^+$	-	Natural Numbers
π	-	Pi
P	-	Power
q	-	Heat Flux
q_a	-	Total Laser Power
Q	-	Specific Heat
Q_a	-	Absorbed Energy
Q_1	-	Energy lost by conduction, convection and radiation
ρ	-	Density of Workpiece
R	-	Beam Radius
r	-	Radial Distance from Origin
t	-	Total Cutting Time
T	-	Temperature
T_0	-	Ambient Temperature
ΔT_m	-	Change of melting Temperature with respect to Ambient Temperature
ΔT_v	-	Change of vaporization temperature with respect to ambient

u_x	-	Traverse Velocity of Heat Source in x – direction
u_c	-	Cutting Speed
V	-	Volume of Cut
V_s	-	Laser Speed
w_k	-	Kerf Width
$\emptyset$	-	Unknown Analytic Function
φ	-	Linear Transformation of x Coordinates
z	-	Z - direction from Workpiece
$\frac{\partial T}{\partial z}$	-	Rate of change of temperature in z – direction
$\frac{\partial T}{\partial y}$	-	Rate of change of temperature in y – direction
$\frac{\partial T}{\partial \varphi}$	-	Rate of change of temperature in x – direction
$\frac{\partial T}{\partial r}$	-	Rate of change of temperature in r – direction

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Overview

The rapid growth of economics since last two decades has brought out a brand new perspective which emphasizes on quality rather than increase productivity. This can be observed through several conditions such as, demand for high quality products, growth of competitors, reduce waste, shorten lead time, customer oriented, increase profitability, etc. Hence, a new concept is necessary to enlarge the quality assessment in manufacturing factors due to global competition. Consequently, it led to the birth of total quality management (TQM) and its by-products such as ISO 9000, DMAIC and Lean Six Sigma. Those ideas highlighted the importance of organization-wide effort and its capability to produce high quality products at lowest cost. Besides that, those concepts have their common features such as redefined the concept of quality, require involvement from top to floor management, customer oriented, streamlining principles, and robust to variations.

TQM is a continuous effort of an organization to implement awareness regarding continuous improve its ability to produce quality product to the end users. Moreover, TQM had eventually penetrated into both business and management strategy to enhance both business and management process in an organization. The methodology of implementing TQM is called Lean Six Sigma DMAIC or DMAIC alone. DMAIC is a streamlining process or framework to conduct any Six Sigma projects. Also, DMAIC is a data driven process and its improvement process can be either open, close or cycle loop. The application of DMAIC can be found in most of

the industry such as biomedical, construction, services, mechanical, maintenance etc. which seek for a sustainable and improved solutions to a problems. DMAIC approach also aims to optimize process, robust control, and to revise current methods or strategies for various case studies in industries.

Tough economic conditions and rapidly rising costs continue to strain higher education institutions' budgets, especially for machinery maintenance operations. [a] Hence, the well-known DMAIC approach could be used to provide deepen insights into machining process in order to reduce the probability of machine failure results by both human and procedural errors. Eventually, it helps to reduce maintenance budget through optimizing machining process rather than in house maintenance alone.

1.2 Background of Study

Lean six sigma is a methodology that relies on a collaborative team effort to improve performance by systematically removing waste; combining lean manufacturing or lean enterprise and Six Sigma to eliminate the eight kinds of waste: defects, overproduction, waiting, non-utilized talent, transportation, inventory, motion, extra-processing which summarized in the acronym (DOWNTIME). [b] Lean mindset was first distinguished through viewers of the Toyota Production System (TPS) in early of the 1940s, which highlighted a context of eliminating waste with the goal of creating value. [c] Lean thinking has substituted the conventional of manufacturer "push" to customer "pull" process such that produce on the basis of customers' demand. A broader sense of lean thinking underlies on developing reasoning ability rather than force them accomplished tasks in a ready-made deriving system. Lean thinking implied a flexible response, knowledge drive, and continuous improvement among individual in order to achieve a common goal of an organization. Six Sigma was first initiated by the CEO of General Electric (GE), Jack Welsh as central of his business development strategies. The idea was emphasized on quality improvement effort which was aligned to the needs of the business. [1] Six sigma explores the possibility of improving output by identifying the cause as well as minimizing the

variability in the process. The approach of implementing Six Sigma involves the use of statistical and non-statistical tools to evaluate a structured system or an environment for the purpose of creating higher quality output. For so many years, Lean advocated Six Sigma did not directly clarify speed, flow and waste. Meanwhile, Six Sigma pointed out that Lean approach is not able to solving variability and optimizing issues [2]. Hence, one unified approach emerges when Lean cooperate with Six Sigma to compromise each other.

Lean Six Sigma is a long-term project based approach which lasts for several months and the key to success rely on the proper techniques for a given problem. The integration of Lean and Six Sigma has provided by seven principles as shown below:

i. Focus on customer (customer pull or customer driven process) [3]
ii. Identified and understand the overall processes include how the job has been done [3]
iii. Manage, improve and smooth the process flow by developing reasoning among individuals [3]
iv. Eliminate non value added process or waste [3]
v. Reduce the cause of variability [3]
vi. Involve and equip the people in the process by way of managing the human aspects. [3]
vii. Embark improvement activities in a systematical way [3]

There are three well-known approaches which well described the "five phase – seven principle" of Lean Six Sigma project methodology and they are:

i. DMAIC (Define – Measure – Analyze – Improve – Control)
ii. DMADV (Define – Measure – Analyze – Design – Verify)
iii. DMARC (Define – Measure – Analyze –Redesign – Control)

However, the backbone of the entire dissertation was enclosed with DMAIC methodology which were used to describe the laser machining capability of EPILOG Legend 36 Ext Laser Cutting Machine. And, the outcome is to optimize machining parameters of this machine. The distinguishing between DMAIC and DMADV depends on the consideration of redesign on existing process in order to meet the level

of customer specification. Occasionally, the application of DMAIC was treated as a strategic to provide a total solution in enhancing processes while reducing wastes as shown in Figure 1.1 in normal operation under economic stakes.

Figure 1.1 8 Forms of Waste [d]

1.3 Research Problem

The entire research in this dissertation would be devoted to analyze the potential causes of failure for one of the laser cut machines, namely EPILOG LEGEND 36 EXT 9000 Series in the FKM fabrication lab. The machine has several serious recorded malfunction and break down event since 2014. Also, the accumulated maintenance overhead costs incurred over the past two years were roughly about RM 10,000. And, most of the expenditure are predominated by maintenance services provided by outside vendors. This decision apparently inevitable since it involved

replacement of crucial parts from sole distributor outside the country. Hence, the only way to do is to limit the amount of usage.

However, the most interesting is breakdown event still remains high even though the malfunction parts has replaced. And, there's no evidence shows any results of maintenance negligence. In this scenario, machining operation and procedure may become the focus of attention.

A quality system often demands a documentation which clarifies regular and standardized operation. However, there is a lack of information regarding process parameter, optimizing control and procedural in laser cut machining from supplier's manual. Hence, machining operations are under supervision for most of the times. Occasionally, some laser cutting operation even required assistance from experienced technicians. [4] For this reason, most of the research and machining process is forbidden because the improper machining procedure and parameters may harmful to the machine.

1.4 Research Objectives

To optimize cutting parameters of acrylic on EPILOG Legend 36Ext by using Lean Six Sigma and develop Standard Operating Procedure (SOP) and maintenance.

1.5 Scope of Study

The scope of study of this project is summarized as follows:

i. To examine the cause of failure for EPILOG Legend 36Ext laser cutting machine via DMAIC, a Lean Six Sigma methodology.
ii. Only one of the most influential factors which affect the overall performance will be determined from analyze phase and to be studied.

iii. Optimum cutting parameter, machine settings, and standard of procedure will be developed for acrylic material.
iv. To improve and revise the existing machining strategies in order to ensure that the quality of cut will continuously improve and sustain.

1.6 Significance of Study

The primordial purpose of this study is to provide recommendations and insights towards maintenance costs incurred in EPILOG Legend 36Ext laser cutting machine. Moreover, the importance of this study addresses the essential of shifting focus from a business strategy tool into a standardized machining strategy through optimizing machining process. However, the ideas were set forth from lean six sigma standpoint, which was often regarded as a business strategic for improving enterprise profitability. [5]

Second, this study also provides a deepen insight towards lean six sigma methodology and its capability to eliminate nonproductive elements in maintenance management. The constructive mapping process enables maintenance staff and management level understand the essence of customer pull (student oriented) process and inspiration of creating improvement, control and maintenance plans.

Third, the idea of DMAIC is analogue to a brainstorming process equipped with rigorous statistical tools which is economical instead of long term spending on seeking advices. The results obtained from the process, not merely to enhance the overall performance, but useful for publishing journals.

Eventually, perhaps the ideas of Lean Six Sigma could turn out to be a common practice among individuals in a higher local educational institution and a relief to the strain of budget.

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