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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Manufacturing Engineering

OPTIMIZATION OF DIMPLE CONFIGURATIONS ON HEAT DISSIPATION OF ALUMINIUM FLAT SURFACE

Hema Nanthini A/P Ganesan

Master of Science in Manufacturing Engineering

2018

OPTIMIZATION OF DIMPLE CONFIGURATIONS ON HEAT DISSIPATION OF ALUMINIUM FLAT SURFACE

HEMA NANTHINI A/P GANESAN

**A thesis submitted
in fulfillment of the requirements for the degree of Master of Science
in Manufacturing Engineering**

Faculty of Manufacturing Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2018

DECLARATION

I declare that this thesis entitled "Optimization of Dimple Configurations on Heat Dissipation of Aluminium Flat Surface" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : G. P. [signature]

Name : HEMA NANTHINI A/P GANESAN

Date : 22/11/2018

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 Master of Science in Manufacturing Engineering.

Signature :..

Supervisor Name :DR. MOHD SHAHIR BIN KASIM

Date : 22/11/2018

DEDICATION

This thesis is dedicated to

Almighty god who gave me courage, will power and strength,

my parents for their cares, love, motivations and prayers had helped me to

achieve this goal,

my siblings and friends for their care, encouragement and support

made me complete this study.

ABSTRACT

In the car manufacturing industry, countless inventions, improvements, and modifications are continuously being updated to meet customer expectations. Therefore, engineers and inventors always give higher priority to improving every part of a vehicle. However, there are still numerous reports of customer frustration, especially in medium-priced cars parts reliability. One of the main issues are involves engine mounts, which are exposed to high temperatures from the engine heat, leading to a short life span. An engine mount is the part that holds the engine to the body or to the engine cradle (sub-frame) of the car. The engine mount exposed high heat energy from the engine during the combustion process (130°C). This causes the engine mount to lose its mechanical strength, resulting in a short service life. The lifespan of the engine mount depends on the effectiveness of heat dissipation during dynamic state. Therefore, it is essential to improve the heat transfer of the engine mounting. Thus, the aim of this research is to develop and evaluate a spherical dimple profile for a smooth surface to enhance heat transfer rate. It is widely known that introducing a dimple profile results in improved heat transfer over a surface. This research focuses on geometric modification and optimization of cooling parameters for a spherical dimpled surface of an aluminium block. The aluminium block is used throughout this experiment because it is one of the best conductors of heat. Thus, in this experiment, the dimpled design is the main focus. In this project, experimental and numerical investigation were carried out to examine the cooling effect and flow structure of the spherical dimple profile during steady laminar flow in a wind tunnel. Seventeen different sets of parameters related to the dimple diameter (10-14 mm), dimple orientation (60°-90° angle), and airflow velocity (16-18 m/s) were studied. The Box-Behnken of Response Surface Methodology (RSM) was used as a Design of Experiments (DoE) tool to evaluate the effect of these parameters on cooling time. This work applies Analysis of Variance (ANOVA) in order to establish the significant effect of the input parameters. ANSYS Fluent software was used as a simulation tool to analyze the flow structure of the dimpled surface. The optimal cooling time is produced from the experiment is 7.23 minutes with a relative error of 5.24% compared to the prediction results. The optimal parameters are a dimple diameter of 12 mm, a dimple orientation angle of 60°, and an airflow velocity of 18 m/s.

ABSTRAK

Dalam industri pembuatan kereta, terdapat banyak penemuan, penambahbaikan dan pengubahsuaian yang sentiasa dikemas kini untuk memenuhi kehendak pelanggan. Oleh itu jurutera dan pereka sentiasa memberi keutamaan yang lebih tinggi kepada penambahbaikan pada setiap bahagian kenderaan. Walau bagaimanapun, masih ada banyak laporan mengenai kekecewaan pelanggan terutama terhadap kebolehpercayaan komponen kategori kereta murah. Salah satu isu adalah mengenai pemegang enjin yang mengalami suhu tinggi daripada haba enjin dan membawa kepada jangka hayat yang pendek. Pemegang enjin adalah bahagian yang memegang enjin ke badan kenderaan (kerangka). Pemegang enjin menerima tenaga haba yang tinggi daripada enjin semasa proses pembakaran (130°C) di mana ia menyebabkan pemegang enjin kehilangan kekuatan mekanikal dan membawa kepada jangka hayat pendek. Jangka hayat pemegang enjin bergantung kepada keberkesanan pelesapan haba semasa keadaan dinamik. Oleh itu, peningkatan pemindahan haba pemegang enjin adalah penting. Oleh itu, matlamat penyelidikan ini adalah untuk membangunkan dan menilai profil cawak yang sfera pada permukaan licin untuk meningkatkan kadar pemindahan haba pada blok aluminum. Pemilihan aluminum dalam ujikaji ini kerana pengalir haba yang baik. Ujikaji ini lebih fokus kepada rekabentuk cawak. Sudah diketahui umum bahawa memperkenalkan profil cawak menyebabkan peningkatan dalam pemindahan haba ke permukaan. Penyelidikan ini memberi tumpuan kepada pengubahsuaian geometri dan mengoptimumkan parameter pendinginan permukaan cawak yang sfera pada bongkah aluminium. Dalam projek ini, siasatan eksperimen dan berangka telah dijalankan untuk mengkaji kesan penyejukan dan struktur aliran profil cawak sfera semasa aliran laminar mantap dalam terowong angin. Tujuh belas set parameter yang berkaitan dengan diameter cawak (10-14 mm), orientasi cawak (60° - 90° sudut) dan halaju aliran udara (16-18 m / s) telah dikaji. Kaedah Surface Respon Box-Behnken (RSM) digunakan sebagai alat reka bentuk eksperimen (DOE) untuk menilai parameter ini pada masa penyejukan. Kerja ini berkaitan dengan analisis varians (ANOVA) dalam usaha untuk menentukan kesan yang ketara parameter.Perisian ANSYS FLUENT digunakan sebagai alat simulasi untuk menganalisis struktur aliran permukaan yang cawak. Masa penyejukan optimum yang dihasilkan oleh eksperimen adalah sebanyak 7.23 minit dengan ralat relatif sebanyak 5.24% berbanding dengan ramalan. Parameter optimum dan tahapnya adalah diameter cawak 12 mm, orientasi cawak 60° dan halaju aliran udara ialah 18 m/s.

ACKNOWLEDGEMENTS

I am very thankful to Almighty GOD for his blessing and giving me the potency and the ability to complete this master study.

I would like to express my special appreciation and cordial thanks to my supervisor Dr. Mohd Shahir bin Kasim from the Faculty of Manufacturing Engineering Universiti Teknikal Malaysia Melaka (UTeM) for his great support and guidance throughout this study. His countless suggestion and unlimited knowledge at every level of study have contributed for achieving the goal of this study. I wish my greatest gratitude to my co-supervisor Professor Dr. T. Joseph Sahaya Anand for his great supervision and guidance. It was great experience to working with them which make more knowledgeable person.

Particularly, I would also like to express my deepest gratitude to the ex-Dean, Faculty of Mechanical Engineering to Associate Professor Engr. Dr. Noreffendy Tamaldin for giving permission for wind tunnel usage. My acknowledgement also goes to Mr. Faizal bin Jaafar for helping in handling of wind tunnel. I wish to extend my gratitude Mr. Mohd Hanafiah bin Mohd Isa in assisting the fabrication dimple profile.

A big gratitude goes to the Universiti Teknikal Malaysia Melaka for the Research Grant Scheme [PJP/2016/FKP/Hl6/S01485] to complete research successfully.

A special thanks to my beloved parents; Ganesan Kayamboo and Patmabathy Arumugam and also to my siblings for their prayers and moral support for completing this master. Lastly, thank you to everyone who had been to the crucial parts of understanding of this project.

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LIST OF SYMBOLS

Q_{conv}	-	Heat transfer rate of convection
Q	-	Heat transfer rate
A_s	-	Surface area
T_∞	-	Temperature of fluid
T_s	-	Temperature of surface
Re	-	Reynolds number
L	-	Length
W	-	Width
H	-	Height
D,Ø	-	Diameter
Θ	-	Orientation of dimple
h	-	Depth of dimple
V	-	Velocity
d_x	-	Space between center of two dimple in horizontal direction
dy	-	Space between center of two dimple in vertical direction
C_T	-	Cooling Time

LIST OF ABBREVIATIONS

3D	-	Three Dimension
ANOVA	-	Analysis of Variance
CCD	-	Central Composite
CFD	-	Computational Fluid Dynamic
DOE	-	Design of Experiment
FDM	-	Finite Difference Method
FEM	-	Finite Element Method
FVM	-	Finite Volume Method
NVH	-	Noise and Harshness
RSM	-	Response Surface Methodology

LIST OF PUBLICATIONS

Journals:

1. Cooling Effect Efficiency Prediction of Aluminum Dimples Block using DOE Technique, 2018. International Journal of Engineering & Technology. (Accepted) (Scopus)

2. Experimental Investigation on Cooling Effect of Spherical Dimpled Profile Aluminum Block by the Taguchi Method, 2018. *Journal of Advanced Manufacturing Technology (JAMT).* (Accepted)(Scopus)

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4. A Study on Surface Roughness during Fused Deposition Modelling: A Review, 2018. *Journal of Advanced Manufacturing Technology (JAMT),* Vol 12, No 1(1), pp. 25-35. (Scopus)

5. Influence of grinding parameters on surface finish of Inconel 718, 2017. *Journal of Mechanical Engineering*, SI 3(2), 199-209. (Scopus)

CHAPTER 1

INTRODUCTION

1.1 Background of the Project

The automotive industry plays a crucial role in developing a country's economy. The automotive industry consists of five phases, which are commonly known as conceptualities, designing, development, manufacturing, and marketing. Manufacturing is considered the biggest challenge in the automotive industry. This is due to the product quality and reliability, which must always be maintained to ensure a good reputation.

In the car manufacturing industry, countless inventions and modifications are continuously updated to satisfy customer expectations. Therefore, engineers and inventors always give higher priority towards improving every part of a vehicle. Quality Engineers often have to review customer feedback in order to improve product quality. These characteristics have a vital impact on the mechanical performance of the overall system balance. Basically, customer complaints regarding the life span of car parts are always highlighted.

The engine is the most important part of a vehicle. The main function of an engine is to change a potential chemical energy form into mechanical energy. Therefore, the engine can be considered as the soul of the vehicle. Inside the engine, a process called internal combustion takes place, where static motion changes into dynamic motion. In other words, the function of the internal combustion 'heat engine' is to convert potential heat energy contained in the fuel into mechanical work. An engine mount is the part that holds the engine to the body or to the engine cradle (sub-frame) of the car. In a typical car, the engine and transmission are bolted together and held in place by three or four mounts. The mount that holds the transmission is called the transmission mount, while the others are referred to as engine mounts.

Engine mounting are commonly used to provide vibration attenuation and to isolate the vibration source (Ripin and Ean, 2010). This material plays an important role in the efficient functioning of automotive systems. Generally, these engine mounts greatly affect the noise, vibration, and harshness (NVH) characteristics of automobiles (Panda, 2016). A deficiency in the engine mounting of vehicles could lead to excessive engine vibrations and eventual damage to the gearbox components (Yu et al., 2001). In addition, without the rubber mounting the passengers and the driver of the vehicle might be exposed to uncomfortable vibrations from the engine and road excitations (Darsivan and Martono, 2006). From one study on dynamic damping measurement of engine mounts was found important in providing information on dynamic damping characteristics under real operation conditions, as it acts as a damper to damp the vibration and noise created by the engine.

Current engine mounts are usually exposed to high temperature from the engine heat, which causes a reduction in service life. The low heat dissipation of the engine mount can be considered as a factor for its short life span. This is because of the exterior appearances of the engine mount. The rubber engine mount's external surface is very smooth and flat as shown in Figure 1.1. The flat surface area promotes low heat dissipation in the engine mount. Besides that, the temperature of the engine while the car is moving is very high and this affects the performance of the engine mount. This will also cause poor heat transfer in the engine mount. The molecules that bond inside the engine mount are also weakened due to high heat energy. One disadvantage of the engine mount is that it does not undergo maintenance or regular service if it is found problematic; instead, it is usually just replaced with a new one.

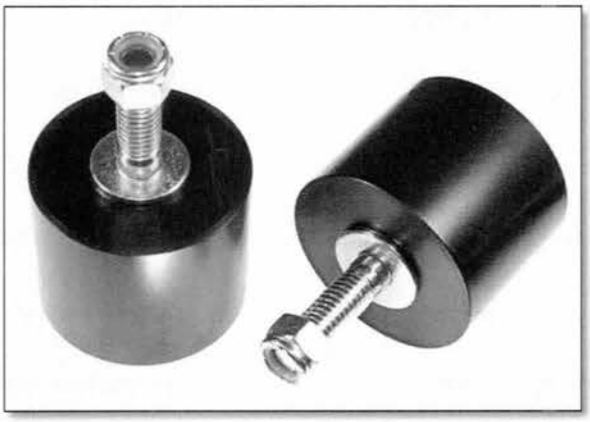

Figure 1.1: The smooth surface of the engine mounting (Longman, 2016)

1.2 Problem Statement

Despite the numerous efforts of automotive manufacturers to innovate materials and the design of the engine mount, there are still countless reports of customer frustration regarding the aspects of noise, vibration, and harshness (NVH); especially with medium-priced cars. Increasingly hostile under-the-hood environment calls for a product with high resistance to vibration and heat. The engine mount is prone to being exposed to high temperature from the engine, which shortens its service life

(Verma et al., 2017). This might also cause misalignment of critical control linkages such as the throttle, clutch, or transmission.

Studies have demonstrated that component life is typically reduced by about 50% for every 10°C increase in operating temperature (Lippincott, 2008). Generally, engine mountings exposed high heat energy from the engine during the combustion process, and this causes the engine mounting to lose its mechanical strength. This is because the excessive heat takes a longer time to dissipate from the engine mounting. The excessive heat causes the molecules that bond inside the engine mounting to weaken. The rate of heat dissipation from the engine mounting can be considered as a factor for its short life span. Generally, the engine mount surface is flat. The flat surface area promotes low heat dissipation in the engine mount. This could lead to the shortened life span of the engine mount. Therefore, it is important to lower the time taken to dissipate the high heat from the engine mounting. Changes must also be made in the engine mount surface area in order to enhance its heat transfer rate. When the surface area is increased, the rate of heat transfer is increased and vice versa. This is expressed via Newton's law of cooling in Eq. (1.1):

$$\dot{Q}_{conv} = h A_s (T_s - T_\infty) \qquad (1.1)$$

Where h is the coefficient of convection heat transfer (Wm^{2} °C), A_s is the surface area (m^2) where the convection heat transfer takes place, T_s is the temperature of the surface, and T_∞ is the fluid temperature, which is sufficiently far from the surface. This equation explains that the rate of heat transfer is directly proportional to surface area. By increasing the surface area of the engine mounting, the heat transfer rate can also be increased.

In the past few years, a few methods were introduced to increase the surface area of engine mounts, which directly improves their heat transfer rate. The methods include introducing pins, protrusions, dimples, and fins. The dimple method is considered the most effective method out of all these methods. This is because by introducing a dimple on a flat surface, it not only increases the heat transfer rate, it also lowers the pressure drop penalties (Zhang et al., 2014). The heat transfer rate is higher because the dimple profile creates vortex pairs, flow separation, and produces a reattachment zone. Creating a dimple profile on a flat surface promotes minimum pressure drop penalties (Beves et al., 2004). Another added advantage in dimple manufacture is the removal of material, which also reduces the cost and weight of the equipment. Introducing a dimpled feature on the engine mounting will promote good heat transfer rate.

Therefore, this research investigates the engine mount surface characteristic. In this study, a dimple profile is introduced on a flat surface. This study focuses on the effects of the dimple feature on heat transfer rate. Therefore, the effect of the dimple profile on cooling time will be studied in more detail in a wind tunnel during the cooling process. In addition, Computational Fluid Dynamics (CFD) will be used to simulate the flow phenomena of the dimple profile during the cooling process. The Finite Element Method (FEM) in CFD is one of the best methods to investigate the dimple profile effects on the heat dissipation rate and flow rate with different cooling process parameters. In CFD, the analysis of one dimple profile can be studied in much more detail and be easily compared to the real process.