



A STUDY OF TYRE CONTOUR DESIGN BY USING BIOMIMICRY CONCEPT: A CASE STUDY OF BIONIC TYRE

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfilment of the requirements for the degree of Bachelor of Manufacturing Engineering (Design)(Hons.). The member of supervisory committee is as follow:



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(TS. DR. SAIFUDIN HAFIZ BIN YAHAYA)

ABSTRAK

Pada masa kini, konsep Biomimikri atau ilmu biologi menjadi sumber inspirasi untuk mewujudkan penyelesaian kreatif dari segi mereka bentuk dalam bidang kejuruteraan. Contohnya, rekabentuk bunga tayar yang diilhamkan daripada konsep Biomimikri juga menjadi tarikan kepada para pengguna semasa pemilihan tayar. Matlamat kajian penyelidikan ini adalah untuk mengkaji konsep Biomimikri yang memberi tumpuan kepada rekabentuk tapak tangan seekor kucing yang diguna pakai bagi rekabentuk bunga tayar dan analisa melalui kaedah analisis. Jenama Bridgestone telah dipilih sebagai tayar sedia ada manakala jenama Continental pula dipilih sebagai tayar bionic. Kedua-dua tayar telah dilukis dengan menggunakan perisian CATIA. Alat lukisan seperti 'Spline' adalah salah satu kaedah reka bentuk yang digunakan untuk mewujudkan konsep Biomimikri. Tambahan pula, tiga kaedah analisis digunakan untuk kedua-dua model reka bentuk seperti analisis statik bukan linear, analisis kelesuan dan analisis dinamik. Kaedah analisis ini berguna untuk menganalisis tekanan, faktor keselamatan, tekanan dan anjakan yang dikenakan ke atas bunga tayar di mana ia akan menunjukkan jangka hayat sesuatu tayar. Hasil yang diperolehi dalam analisis static bukan linear menunjukkan bahawa tekanan maksimum Von Mises yang dikenakan pada reka bentuk tayar bionik jauh lebih rendah daripada reka bentuk yang sedia ada. Kedua-dua model reka bentuk tersebut dapat diterima kerana nilai CV yang melebihi 85 peratus. Selain itu, reka bentuk bionik juga lebih stabil pada tekanan tinggi semasa pengiraan dalam analisis kelesuan. Melalui pengoptimuman reka bentuk, ianya dapat ditunjukkan bahawa reka bentuk bionik mempunyai kesan baik yang sangat ketara berbanding reka bentuk yang sedia ada.

ABSTRACT

Nowadays, Biomimicry concept or biological knowledge is becoming a significant source of inspiration for creating creative solutions to design problems in engineering. For example, a tyre contour design that inspired from biomimicry concept also becoming an attraction for the consumer during tyre selection. The aim of this research study is to examine on Biomimicry concept focusing on cat's paw design that applies to tyre contour design and analyse through method of analysis. Bridgestone brand is selected as conventional tyre while Continental brand is chosen as Bionic tyre. Both tyres were drawn by using CATIA Software. Spline tool is one of the design method that is used to create biomimicry concept. Furthermore, three methods of analysis were used for both design models such as Non-Linear Static analysis, Fatigue Analysis and Dynamic analysis. This methods are useful to analyse the stress, safety factor, pressure and displacement exerted on the tyre contour where it will indicate the lifespan of the tyres. The result that have been obtained in Non Linear Static analysis shows that the maximum Von Mises stress exerted on the bionic tyre design is much lower than the conventional design. Both of the design models can be acceptable due to the value of CV more than 85 percent. Besides that, the bionic design is more stable at high pressure during the calculation in Fatigue analysis. Through the design optimization, it is shown that bionic design had a very significant impact rather than the conventional design.

DEDICATION

Special dedicated to my beloved parents, Mr. Abdul Rahman bin Mokhtar and Mrs. Aslina binti Mohd Amir for giving me moral support, caring, encouragement and patience in helping me physically and mentally. Thank you to my lovely siblings, honourable lecturers and fellow friends for all the encouragement, guidance and supportive in completing my final year project.

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LIST OF ABBREVIATION

| | | |
|--------|---|-----------------------------|
| 2D | - | Two Dimensional |
| 3D | - | Three Dimensional |
| DE | - | Design Efficiency |
| CAD | - | Computer Aided Design |
| CFD | - | Computational Fluid Dynamic |
| CV | - | Coefficient Variation |
| FEA | - | Finite Element Analysis |
| FEM | - | Finite Element Method |
| FLUENT | - | ANSYS Fluid Flow |
| FVM | - | Finite Volume Method |
| S_f | - | Safety Factor |

CHAPTER 1

INTRODUCTION

In this section, the research study is divided into five main subtopic. Starting with the background of the research study, problem statement, briefly explain the significance of research study. Furthermore, the aims of this research study are also stated and this chapter ends with the report organization explanation.

1.1 Background of the Study

Biological knowledge is becoming a significant source of inspiration to find innovative solutions to problems of engineering design and even has enormous potential in formulating ideas that can help companies succeed effectively in a competitive market (Shi et al., 2019). A tyre tread design that inspired from biomimicry concept is also becoming one of the attraction for the consumer during tyre selection for their vehicles rather than conventional tyre. Due to growing importance of environmental sustainability among business managers and customer, the fact that biomimicry created more energy-efficient solutions concept is particularly noteworthy (Kennedy, 2017).

Many elegant solutions to engineering problems have been inspired by biological phenomena. Despite inspired by nature, bionic design or biomimicry, despite being an inspiration for design activities for a long time, has recently gained a role as part of a standard set of approaches to address design issues and under pressure from sustainability concerns. Imani (2017) note that biomimicry can also help people change their precepts towards nature, as nature is not a barrier, but a source of innovation and inspiration.

Pei (2015) proved that bio inspired design for tyre tread compound consist of two impeccably suited system; an adaptable system and a firm one. The adaptable system ensures the most severe transmission of strengths between the tyre and the street surface, while the firm system provides the essential solidity for exact quality treatment, especially at high speeds. One of the tire industry's priorities is to maximize the tyre-road energy distribution by using biomimicry concept (Ivanovic et al., 2017). All tyres must perform several task simultaneously in order to become the first customer choice among all of the tyre. The tyre should have low rolling resistance during driving to reduce fuel consumption, high sliding resistance during braking to shorten stop distances and it also should be durable and ensure silent driving.

Deaton (2010) expressed a tyre is made up of more than just rubber. Tyres are a sophisticated mix of materials that includes high-tech fabrics, natural and synthetic rubbers and even steel. Oponeo (2016) estimates that these areas account for 85% of the rubber of the tyre, with 35% in the tread and carcass as well as 15% in the side wall. The majority of 15% is used in the liner.

According to Anne and Evans (2006), the components of the tyre can be specified into inner liner, bead, casing ply, bead wires, rubber sidewalls and the tread. Inner liner is a rubber compound bonded to the inside cord body that retains air under pressure. The sidewall is considered the area of a tyre from the bead to the rubber. Besides that, tyre beads bring the tyre onto the wheel's rim or outer edge. The function of the casing ply is to resist high pressure up to 15 kilograms of force. Tread is the tyre component that comes into contact with the road. The design of the tyre's contour have to balance resistance, fuel economy and other characteristic of the tyre.

The pattern of the tyre contour is the arrangement of blocks, grooves and voids, sipes and channels designed into the tread to enhance its grip on the road (Sridharan and Sivaramakrishnan, 2012). Grooves are channels that running between the tread ribs circumferentially around the tyre. A tyre with less grooves will gives more mechanical grasp. Tread blocks are the raised rubber segments that make contact with the surface whereas the function of the sipes is to enhance all season traction.

1.2 Problem Statement

In these modern day, nearly 170 million of new tyres are being produced a year for automotive industry, medical equipment and others. More than 2.5 billion tires are manufactured annually, making the tyre industry a major consumer of natural rubber. Tyre plays an important role in the automotive manufacturing industry. Till date, customers are even spoiled with choice by lots of tyre manufacturers available. As a result, a customer tends to choose on a tyre that is not available for their vehicle.

Lately, bio-inspired tyre has recently become an attraction rather than a conventional tyre among vehicle users. Conventional tyre has some drawbacks that make it less consumer preferred. Poor handling of transportation is the main drawback to having a conventional tyre rather than a nature concept tire. Poor handling transportation can be category into two types which are driving at speed and overloading of the vehicle.

Driving at high speeds is more likely to cause damage to the tyre rather than low speed. In addition, driving at high speed with a road hazard also has a greater chance of causing tyre damage. It also can cause heat build-up in the tyre including air loss, which can cause tyre damage and increases the wear rate of the tyre. Suyabodha (2017) proved that the lower pressure of the tyre caused the tyre to deform more than the high pressure of the tyre when rotating on the flat surface which caused high loss of hysteresis. Thus it would lead to high fuel consumption or accident due to failure in controlling the vehicle.

The tyre pattern design may lead to sound or noise problem. Ball (1995) specified that a well-designed tread pattern limits itself to a quieter, swishing song. Noise problem from tyres could also be the result of something faulty, such as abnormal tyre wear (Jerew, 2019). Sandhu et al. (2016) proved high stress exerts during driving also could give noise problem due to screeching sound caused by extreme vibration. Different design of tyre patterns would give an effect in reducing the stress exerts by the tyres during cornering or braking which can also effect in reducing the noise problem.

1.3 Objectives of the Study

The objectives for this research study are stated as follow:

- I. To study on the Biomimicry concept such as cat's paw in tyre contour design.
- II. To design the pattern using Biomimicry's concept.
- III. To redesign the conventional tyre using CATIA Software.
- IV. To analyse both design models using a method of analyses.
- V. To validate data of analysis by using Design Efficiency (DE) and Coefficient of Variation (CV).

1.4 Scope of the research

This research study are focusing on the design of the cat's paw only. Besides that, the tyre consist variety of terminology and tyre contour is chosen as the platform to apply the design of the cat's paw. Design modelling will be generated by using the CATIA software. Three types of method analysis are conducted in order to determine the value of Von Mises stress, displacement for Non Linear Static Analysis while maximum velocity and pressure for Dynamic Analysis. In addition, design optimization will be done in this research study to support selection of the optimal design among many parameters.

1.5 Significance of the study

The result of this research study will redound to the benefit of passenger car users considering certain appropriate methods that play a major role in these modern days. Biomimicry concept for this research study will be focusing more on cat's paw design in term of its features. A cat's paw widened when the cat brakes, thus emitting more force to the ground than it would if the cat walked, or in our case if the car was normally driving. This bionic design has enhanced this performance characteristic by applying the cat's paw design on the tyre contour. The design model of bionic tyre is chosen from the brand of Continental Tyre.

Both design models will be analysed by using non-linear static, fatigue and dynamic analysis. With the correct calculation of displacement and pressure due to the static load, non-linear static analysis radiates. The benefit that would be gained from Non-Linear Static analysis is the more prevalent is the deflection of the tyre at higher burdens, which gives the vehicle more cushioning and thus raises the moving resistance when considering the tyre with impressive esteem. It is more effective at higher load applications.

Fatigue is one of the process of analysis where it takes place due to the repetitive application of pack and should be at a flat surface of the yield point and safety factor, S_f will be determined using appropriate tools. Fatigue analysis is useful by using some appropriate method for the reliability design of a tyre and fatigue life of passenger car tyre. Dynamic analysis of the tyre contour design can improve the ability to control and optimize the noise and vibrations arising from the contact between road surface and a moving tyre.

Design Efficiency (DE) and Coefficient of Variation (CV) will be used as benchmarking for this study. The purpose of Coefficient of Variation (CV) is to determine the stability between the tyre and surface of the road. For the result, the higher the value of Coefficient of Variation (CV), the greater the value of dispersion. However, Design Efficiency (DE) measures all techniques to optimize the design so that maximum capacity can be provided.

1.6 Report Organization

Chapter 1 indicates the research study's introduction. This report begins by discussing the background of the research, problem statement, the study's significance, research goals and organization of the report. Initially, the background of the study will clarify the hierarchy of tyre and tyre's characteristic. Moreover, the discussion about the problem related to the conventional tyre and bionic tyre will be clearly stated. The significance of the study continues in this chapter where the importance of biomimicry concept for tyre to the customer will be illustrated.

Chapter 2 reviews on the background and information about the bionic tyres, features and analysis. This chapter will begin with the definition of biomimicry and its advantages

including the application of biomimicry in industry. The explanation about the nature concept focusing on cat's paw that is applied on tyre contour also will be discussed through this chapter. The next subtopic will be followed by the overview of the tyre and its feature in tyre terminology. Furthermore, the history and types of tyre contour design will be reviews in this chapters. The materials of the tyre that is used will also briefly explained. The features of conventional tyre and bionic tyre will be clearly stated in this chapter such as Biomimicry's concept and application of Biomimicry.

Chapter 3 elaborates methodology which include the process flow chart and methodology of this research study. This chapter will explain an introduction to the conventional tyre (Bridgestone ECOPIA EP300) and Biomimicry's concept tyre (Continental Premium Contact). Furthermore, the process flow diagram of designing the tyre contour design for both conventional tyre and bionic tyre design will be discussed in this chapter. 2D and 3D model development will be constructed by using CATIA Software and analysis of simulation which is non-linear static will be obtained for both design models. The process flow diagram for Non-linear static, fatigue and dynamic analysis will be discussed in this chapter. Non-linear static analysis radiates with the correct calculation of displacement and stress due to the variation of static load. Newton Interpolation Polynomial is used as fatigue predictor to estimate the fatigue life of both design models and this method is used for fatigue analysis. During optimization process, Design Efficiency (DE) and Coefficient of Variation (CV) will be utilized for both conventional tyre and bionic tyre design. ANSYS Fluid Flow (FLUENT) software is used to test all concept models for dynamic analysis.

Chapter 4 narrates the result and discussion of the Non Linear Static analysis and Fatigue analysis. This chapter explains about the results and the discussion based on the result that have been obtained. The Non Linear Static analysis will be conducted by using Solidworks Software to determine the Von Mises stress and displacement on both existing and improvement design models. Besides that, Newton Interpolation method is used for calculating the initial pressure and safety factor value. Then, the design optimization for both models will be computed. However, design validation for both design models will be determined by computing the Design Efficiency (DE). The explanation for finding discussion will be covered in this chapter.

Chapter 5 describes dynamic analysis where the design model is analysed by using ANSYS Fluid Flow (FLUENT) package. ANSYS Fluid Flow package is used to meet the requirement of this study by considering the velocity and pressure in moving condition. Materials that have been chosen will examine existing design models as well as improvements design models. The design validation for both design models will be calculated by computing Coefficient of Variation (CV). More information in this chapter will be discussed thoroughly.

Chapter 6 displays about the conclusions and recommendation regarding the entire of the research study. This chapter describes the conclusions in which it would be known at the end of the study whether or not all of the objectives have been accomplished. An understanding will be formed on the study of the bionic tyre based on the result of analysis from the previous chapter. The comparison of conventional tyre design and bionic tyre design with their respective specification will be used as supporting evidence for assessing whether or not the goals have been achieved. In addition, the research related to the suggestion for recommendation will be identified based on the results obtained for future research through method of analysis.

CHAPTER 2

LITERATURE REVIEW

This chapter provides the reviews from the previous researches on the Biomimicry concept regarding to the advantages and applications of the Biomimicry concept. Furthermore, the discussion about the overview of the tyre will be clearly explained throughout this research. General types of tyre contour design which are known as directional, symmetrical, asymmetrical and directional/asymmetrical are also discussed in this chapter. This chapter begins with the explanation about the detail of Biomimicry concept in the next section.

2.1 Biomimicry Concept

Biomimicry concept which is also known as Bio Inspired Design (BID) has includes the transformation of new innovations based on the knowledge that is gained from the natural world. Katherine et al. (2014) stated that bio-inspired design and the wider field of design by analogy area have been the basis for many innovative designs throughout history; yet much remains to be understood about these design practices, their cognitive underlying mechanisms, and preferred ways of teaching and supporting them. An example of such an approach is a Vibram shoes inspired from a gecko's foot. The manufacturer claims they have a natural feel and their grips helps walking, riding and climbing (Ryan, 2014).