UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CONCEPTUALISATION OF MODULAR AIRLESS TYRE USING KANO, QFD AND FAST METHODOLOGIES

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MASTER OF SCIENCE IN MANUFACTURING ENGINEERING

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A project report submitted
in fulfillment of the requirements for the degree of
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DECLARATION

I declare that this project entitled "Conceptualisation of Modular Airless Tyre Using Kano, QFD and FAST Methodologies" is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

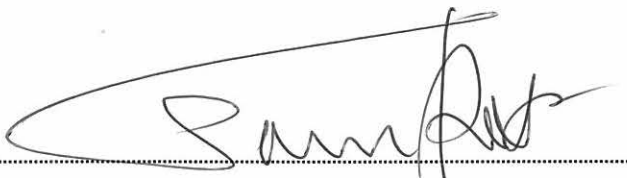
Signature : 

Name : NURUL HANIS BINTI ABDULLAH

Date : 23 SEPTEMBER 2022

APPROVAL

I hereby declare that I have checked this project report and in my opinion this project report is sufficient in terms of scope and quality as a partial fulfillment of Master of Manufacturing Engineering (Industrial Engineering).

Signature : 

Supervisor Name : PROFESSOR IR. DR. SIVARAO A/L SUBRAMONIAN

Date : 23/9/22

DEDICATION

This study is dedicated to beloved mother Zainab, who have been my source of inspiration and who have granted me strength when I thought of giving up, who persist to provide her moral, spritual, emotional and financial support. To my relatives, educators, friends and classmates who shared their words of advice and encouragement to finish this study.

Lastly, I had also dedicated this study to Allah, Subhanahu Wa Ta'ala, thank you for guidance, strength, power of mind, protection and willingness, and for giving me a health.

ABSTRACT

Begun in 2008, one of the more fascinating developments in the history of the automotive tyre is the modern concept of the airless tyre. Airless tyres have been getting a ton of media attention recently with Michelin's "Tweel" being praised as the most amazing bit of tyre technology since the invention of the radial tyre. According to a recent market analysis, airless tyre manufacturers are still rated low in terms of functional innovation, mainly focusing their effort on the shape and appearance of the frame. The existing airless tyre has difficulty modifying after it has been manufactured, as well as its lack of adaptability. This project presents the new concept of modular airless tyre developed using Kano, Quality Function Deployment (QFD), and Function Analysis System Technique (FAST) method. Functional analysis is used to identify and analyse interactions of airless tyre components. The user requirements are gathered, analysed using Kawakita Jiro (KJ)/ affinity method for hierarchical analysis and clustered according to the Kano model, and the importance of each group is determined. Then, the function of the MAT body is decomposed using FAST method to obtain the function structure. Finally, the function structure of the MAT is imported into the "requirement-function" of the quality house model to establish the correlation between user requirements and MAT function, and a function system diagram is created. The lack of adjustability of airless tyre is attributed to insufficient interaction between the spoke, hub, and outer ring. The outcome of the experimental design study shows that the proposed function-combining design method allows the designer to effectively grasp real user requirements including safety, simplicity, segmentation, ease of maintenance and reliability are refined into specific solution strategies that are used to generate three new innovative conceptual sketches. Then, design a MAT using a streamlined design process, thus resulting in better designs that meet user expectations. The result shows that concept 2 are the final optimized design based on identified basic function and function were ranked according to importance level.

ABSTRAK

Bermula pada tahun 2008, salah satu perkembangan yang lebih menarik dalam sejarah tayar automotif adalah konsep moden tayar tanpa udara. Tayar tanpa udara telah mendapat banyak perhatian media baru-baru ini dengan "Tweel" Michelin dipuji sebagai teknologi tayar yang paling menakjubkan sejak penciptaan tayar radial. Menurut analisis pasaran baru-baru ini, pengeluar tayar tanpa udara masih dinilai rendah dari segi inovasi fungsional, terutamanya menumpukan usaha mereka pada bentuk dan rupa bingkai. Tayar tanpa udara sedia ada mengalami kesukaran mengubah suai selepas ia dihasilkan, serta kekurangan kebolehsuaiannya. Projek ini membentangkan konsep baru tayar tanpa udara modular yang dibangunkan menggunakan Kano, Penggunaan Fungsi Kualiti (QFD), dan kaedah Teknik Sistem Analisis Fungsi (FAST). Analisis fungsional digunakan untuk mengenal pasti dan menganalisis interaksi komponen tayar tanpa udara. Keperluan pengguna dikumpulkan, dianalisis menggunakan kaedah pertalian Kawakita Jiro (KJ)/ untuk analisis hierarki dan dikumpulkan mengikut model Kano, dan kepentingan setiap kumpulan ditentukan. Kemudian, fungsi badan MAT terurai menggunakan kaedah FAST untuk mendapatkan struktur fungsi. Akhirnya, struktur fungsi MAT diimport ke dalam "fungsi keperluan" model rumah berkualiti untuk mewujudkan korelasi antara keperluan pengguna dan fungsi MAT, dan gambarajah sistem fungsi dicipta. Kekurangan penyesuaian tayar tanpa udara disebabkan oleh interaksi yang tidak mencukupi antara jejari, hab, dan cincin luar. Hasil kajian reka bentuk eksperimen menunjukkan bahawa kaedah reka bentuk gabungan fungsi yang dicadangkan membolehkan pereka memahami keperluan pengguna sebenar dengan berkesan termasuk keselamatan, kesederhanaan, segmentasi, kemudahan penyelenggaraan dan kebolehpercayaan diperhalusi ke dalam strategi penyelesaian tertentu yang digunakan untuk menghasilkan tiga lakaran konsep inovatif baru. Kemudian, reka bentuk MAT menggunakan proses reka bentuk yang diperkemas, sehingga menghasilkan reka bentuk yang lebih baik yang memenuhi jangkaan pengguna. Hasilnya menunjukkan bahawa konsep 2 adalah reka bentuk yang dioptimumkan akhir berdasarkan fungsi dan fungsi asas yang dikenal pasti mengikut tahap kepentingan.

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Last but not least, from the bottom of my heart a gratitude to my my beloved parents for their endless support, love and prayers. Finally, thank you to all the individual(s) who had provided me the assistance, support and inspiration to embark on my study.

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AHP	-	Analytic Hierarchy Process
ANP	-	Analytic Network Process
Al	-	Aluminium
3D	-	3 Dimension
CAD	-	Computer-Aided Design
CAGR	-	Compound Annual Growth Rate
CEC	-	Cause-And-Effect Chain
FAST	-	Function Analysis System Technique
FAM	-	Function Analysis Model
FEA	-	Finite Element Analysis
KJ	-	Kawakita Jiro
MAT	-	Modular Airless Tyre
ME	-	Mechanical Elastic
PU	-	Polyurethane
PFD	-	Problem Formulation Diagram
QFD	-	Quality Function Deployment
TRIZ	-	Theory of Innovation Problem Solving

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CHAPTER 1

INTRODUCTION

1.1 Background

The performance of tyres is engineered to fulfil the riding, handling, and traction requirements of the vehicle while maintaining the necessary safety performance and quality. The fundamental purpose of tyres is to act as the vehicle's interaction with the road. Friction between the road and the tyres is what allows cars to go forward, stop, and turn corners. Cheah et al. (2016) stated that tyre tread patterns permit allowing water to dissipate from the tyre-road contact area while maintaining an acceptable balance between traction and noise level to reduce hydroplaning.

Rubber members are utilized in tyres to produce cushioning likewise as clearance for the vehicle. The rubber part is secured to the rim of the wheel. A tube is put inside a tube tyre, whereas a tubeless tyre doesn't have one. The tyre may be a circular component that's installed on the rim of the tyre to transmit the vehicle's load from axle to rim (Abhishek & Kumar, 2020).

Rangdale et al. (2018) acknowledge that non-pneumatic tyres (NPTs) can achieve suspension performance, better handling, and better driving comfort. Driving safety and comfort comes from the suspension system of a vehicle that connects the frame to the road. The major purpose of the suspension system is to improve the overall performance of the vehicle as it rolls down the road. In addition to aiding in the absorption of road imperfections, the suspension system ensures a healthy and pleasurable ride. The suspension system consists of springs, shock absorbers, bars, linkages, and, most importantly, tyres. Sassi et al. (2006) mentioned that although tyres have made great strides in terms of safety, performance, and wear, they still require more attention than most car components.

Continuous efforts are revamped over the years to boost the planning of the pneumatic tyres. However, even this design of the tyre has drawbacks, like deflation because of punctures, the requirement for routine maintenance to take care of the right atmospheric pressure, and the lack of durability. Additionally, Rhyne et al. (2006) described that since

this design of the tire is subject to varied constraints, there's no optimal design so far. They proposed a non-pneumatic tyre design called a Tweel as an answer to those prevalent issues and also described this design as not only possessing the essential characteristics of the tyre but also expanding the restricted design space offered by the tire. Figure 1.1 shows a prototype Tweel that was tested at Michelin and The Clemson University International Center for Automotive Research (CU-ICAR).

Figure 1.1: Tweel Prototype at CU-ICAR (Rhyne et al., 2006)

Advantages of airless tyre include no maintenance, high impact resistance, the ability to work with a partially damaged tyre, and use on rough terrain. In the case of an airless tyre, controlling pressure and energy losses is as simple as selecting the optimal support structure and material composition. A tread, a shear beam (equivalent to the carcass in a pneumatic tyre) or an elastic ring, a deformable supporting structure, and a rim comprise the components of the general airless tyre design, as depicted in Figure 1.2. Hryciów et al. (2020) acknowledge that the tyre's rim and tread of the tyre serve the same purpose as those of traditional pneumatic tyres. The shear beam may have a core, solid or of a certain geometry) sandwiched between two low-deformation-modulus membranes.

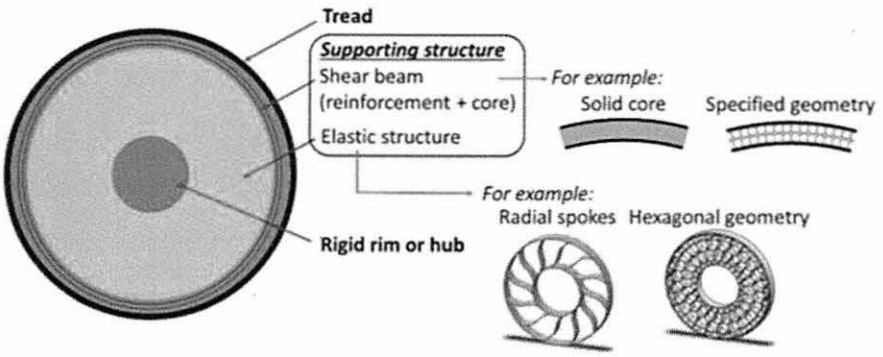

Figure 1.2: General concept of airless tyre (Hryciów et al., 2020)

1.2 Problem Statement

Airless tyres are difficult to design because modern airless tyres are still at an early stage of development (Niky, 2022). According to recent market analysis, Malaysia airless tyre manufactures are still rated low in terms of functional innovation, mainly focusing their efforts on the shape and appearance of the frame. Its functionality is the most important aspect of the airless tyre designing, which means that product designers need to have an in-depth understanding of the user requirements.

One limit to the user requirement on durability of tyres is heating at hyper-velocities. The thermal problem concerns pneumatic and airless tyres. The optimum mode of tyres is the temperature from 70 to 750 Celsius. When heated to 1000 Celsius the durability and bond strength between rubber and its cord is reduced up two times. The proposal of a new structure of the tyre material and thermal effects need to be considered (Evseev et al., 2019).

Nevertheless, because of the pressurised air containment, they are simply punctured and eventually burst, resulting in deadly accidents. Also, the air pressure in the tyre should be kept within the proper range to avoid potential pain for the user, such as pressure loss produced by leaks around the wheel rim and oxygen absorption in rubber, which leads to flat tyres in contact areas and increases wear and fuel consumption. To address this issue, researchers created an innovative concept called an airless tyre, which does not require compressed air to work (Manesh et al., 2012).

Attempts are made to make flat proof which will provide identical mechanical qualities because the air trapped inside the tyre since the start of the 20th century. There's no need for periodic maintenance to refill the tyres with air and maintain an appropriate internal

pressure with the revolutionary technology of airless tyres. This system minimises the danger of punctures and greatly improves the vehicle's safety.

Dronavajhula et al., (2021) studied on airless tyre of different spoke structure on aircraft also consider the safety or airless tyre, and that a lot of its value will be in a spoke design. The researcher mentions that with airless tyre there are no blow-outs and road accidents are inherently reduced. The design relies on solid internal hub, attached to an axle and enveloped in polyurethane. This combination forms a wedge pattern that can absorb the effects of the terrain the wheels are used on.

As the source of hazard in pneumatic tyre is mainly due to their dependence on air, by introducing the concept of airless tyre such limitations can be avoided. This disadvantage of puncture can be removed by introducing airless tyre that have improved handling and increased surface traction. However, one of the most major disadvantages of the airless tyre is that once created, it cannot be changed and lack of adjustability. A new set of airless tyres would be required if the vehicle required a different quiet setting (Kalahastimath, 2021).

1.3 Research Objective

Several research objectives have been established in order to solve the aforementioned problems. The main aim of this research is to propose a user requirements-oriented Modular Airless Tyre (MAT) design method centered on finding the best combination of functions. Specifically, the objectives are as follows:

a) To identify and analyse the interactions of the airless tyre system's core components.

b) To carry out the functional design of a Modular Airless Tyre (MAT) by combining the Kano model, Quality Function Deployment (QFD), and Function Analysis System Technique (FAST).

c) To determine the final optimization design of Modular Airless Tyre (MAT).

1.4 Scope of Research

The scope of this research are as follows:

- Focused on the conceptualisation process where Kano model approach is used as a concept generation while QFD method is used for concept selection.
- This study uses a quantitative survey method as the best to meet the customer need. User requirement of MAT users were gathered through user interviews.

Candidate interviewees were selected based on previous experience buying or using pneumtic tyre. After that, 60 respondent were contributed for the questionnaire of "Malaysians' Acceptance of Modular Airless Tyre" to analyse the problem using a pneumatic tyre on Malaysian user, analyse the customer requirement for the innovation, and figure out the worth of a high-quality product to the user.

- The interaction of car's airless tyre core components are identified and analysed using functional analysis.
- Based on identified inventive principles, specific solution strategies are developed, which are used to construct the conceptual sketch of a Modular Airless Tyre (MAT).
- The FAST and QFD method is used to evaluate the concept generated where a final concept of MAT is made from the evaluation.

1.5 Significant/Importance of Study

In terms of safety, durability, and wear, tyres have come a long way, but requires more attention than majority of the car components. To improve vehicle protection, these factors necessitate both well-known design improvements and the quest for new wheeled mover design solutions, one of which is the use of wheels with airless tyre. Airless tyre has pneumatic characteristics with pneumatic tyre such as load carrying capacity and ride comfort, and it cannot be punctured because it does not have pressurised air cavity. This work looks forward to that new concept of modular airless tyre might be a benchmark study when developing modular airless tyre. The new concept hopes to solve lack of versatility issues of the current airless tyre.

1.6 Organization of The Report/Thesis

Based on the objectives previously presented and, on the approach, proposed before, this thesis is made up of five (5) chapters, which contents are summarized as follows:

- Chapter 1. Introduction. The topic of the project is introduced in this chapter, and the reader is given a brief overview of the study. The project's context, problem statement, goals, scope, significant/important findings, report organisation, and overview are all included in this chapter.