DESIGN AND FABRICATION OF A
REDUCED SCALE TIRE TEST MACHINE

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SUPERVISOR DECLARATION

"I hereby declare that I have read this thesis and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Automotive)"

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Supervisor: ………………………..

Date: ………………………..

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This report is submitted in partial fulfillment of the requirements for the award of a Bachelor of Mechanical Engineering (Automotive)

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DECLARATION

"I hereby declare that the work in this report is my own except for summaries and quotations which have been duly acknowledged."

Signature: ……………………….

Author: ……………………….

Date: ……………………….

Gratitude to PSM supervisor

PSM panel

Family and

Course mates

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ABSTRAK

Ia adalah penting untuk mengkaji daya maju oleh tayar untuk memahami reaksi dinamik kenderaan yang menggambarkan pelbagai peristiwa-peristiwa yang berlaku dalam keadaan memandu yang sebenar. Penjanaan kuasa-kuasa tayar berdasarkan nisbah slip membujur dan tayar slip sudut input dikaji. Selain itu, skala penuh ujian peralatan tayar dan kelebihan mesin skala Kurangkan telah dikaji. Projek ini memberi tumpuan kepada pembangunan mesin ujian tayar yang berskala rendah yang dapat menentukan kekukuhan tayar membujur dan ketegangan memborong daripada satu kepada skala kelima kenderaan kawalan jauh. Untuk membangunkan mesin ini, pelbagai reka bentuk konsep telah dijana dan reka bentuk yang paling sesuai dipilih dengan menggunakan keputusan berat badan kaedah matriks. Berdasarkan reka bentuk yang dipilih, reka bentuk terperinci termasuk bil komponen mekanikal dan bil komponen elektrik yang menentukan fungsi tertentu setiap komponen untuk menjalankan fungsi yang ditetapkan. Mesin ujian tayar berskala rendah membina dari mekanisme mudah yang menggunakan motor DC untuk merangsang gendang berputar tayar di kedudukan pegun, pengekod sudut untuk mengukur kelajuan putaran tayar, motor pelangkah untuk menyediakan roda mengemudi sudut, Prony brek digunakan untuk mendapatkan tindak balas dijana oleh tayar pada tolok membujur dan tekanan yang digunakan untuk mengukur arah sisi. Analisis tekanan dilakukan pada kerangka struktur mesin untuk mengelakkan kegagalan struktur. Model tayar Dugoff dibangunkan untuk menyediakan maklumat mengenai ketegangan membujur dan ketegangan memborong tayar. Ujian berfungsi adalah penting untuk memastikan mesin ujian tayar boleh berfungsi dengan baik dan dapat menentukan tayar ketegangan dan ketegangan memborong yang membolehkan penyelidik dan jurutera untuk menyiasat mengurangkan ciri-ciri tayar.

ABSTRACT

It is important to study forces developed by the tire to understand the dynamic behavior of the vehicle which reflect multiple events that occur under real driving condition. The generation of these tire forces based on the longitudinal slip ratio and tire slip angle input is studied. Besides, the full scale tire test apparatus and the advantages of reduce scale machine is studied. This project is focus on development of a reduce scale tire test machine which able to determine the tire longitudinal stiffness and cornering stiffness of a one to fifth scale remote control vehicle. To develop this machine, multiple conceptual designs have generated and the most appropriate design is selected by using weight decision matrix method. Based on the selected design, detail design included bill of mechanical component and bill of electrical component which determined the specific function of every component to carry out specifies task. Reduce scale tire test machine build up from simple mechanism which used a DC motor to stimulate a drum to rotate the tire in stationary position, angular encoder to measure tire rotational speed, a stepper motor to provide wheel steer angle, prony brake used to obtain reaction force generate by tire at longitudinal and strain gauge used to measure lateral direction. Stress analysis is done on the machine structural frame to avoid structural failure. Dugoff tire model is developed to provide tire longitudinal and cornering stiffness information. Functional test is important to ensure tire test machine can work properly and able to determine the tire longitudinal and cornering stiffness which enable the researchers and engineer to investigate reduce scaled tire characteristic

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LIST OF SYMBOLS

σ_y	=	Tire slip angle
σ_x	=	Tire longitudinal slip
V_x	=	Longitudinal velocity of wheel, m/s
ω	=	Angular velocity of wheel, rad/s
$r_{eff}\omega$	=	Rotational velocity of the wheel
α	=	Tire slip angle, rad
δ	=	Steering Angle, rad
μ	=	Coefficient of friction of tire
F_x	=	Longitudinal tire force, N
F_y	=	Lateral tire force, N
F_z	=	Tire vertical force, N
T	=	Torque, Nm
W	=	Weight, g
R	=	Radius, cm

LIST OF APPENDICES

LIST OF ABBREVIATIONS

CAD	Computer Aided Drawing
CATIA	Computer Aided Three-dimensional Interactive Application
DC	Direct Current
FEA	Finite Element Analysis
FEM	Finite Element Method
PSM	Project Sarjana Muda

CHAPTER I

INTRODUCTION

1.1 OVERVIEW

Tire is important to support vertical load while cushioning road shocks, developed longitudinal force for acceleration and braking, develop lateral forces for cornering (Gillespie, 1992). Development of reduced scale tire test machine is essential to determine the tire longitudinal stiffness and cornering stiffness of a reduce scale remote control vehicle. This reduced scale machine focus to determine tire parameter of a one to fifth reduced scale remote control vehicle. These properties of tire are important in tire research and improvement especially in developing a brake caliper and brake pad of a reduced scale vehicle. Reduced scale machine is developed since parameter of a reduced scale tire is similar to the actual scale tire vehicle.

Reduced scale tire test machine build up from simple mechanism to obtain longitudinal force, lateral force, tire rotational speed, tire relative longitudinal speed, wheel steer angle. Design of tire test machine consists of drum to rotate the tire in stationary position, angular encoder to measure tire rotational speed, a stepper motor to provide wheel steer angle, force sensor to obtain reaction force generate by tire at longitudinal and lateral direction.

1.2 PROBLEM STATEMENT

It is important to study tire forces on developed by the tire because the dynamic behavior of the vehicle depends on these forces especially when the vehicle is driven to its limit. By combining these parameters, it is possible to understand multiple events that occur under real driving condition. Therefore, the assumption that tire has linear behavior especially in longitudinal and lateral direction is not true since during extensive steering and throttle or braking inputs by the driver, the tires operates in non-linear region. Besides, for vehicle model simulation purpose, accurate tire parameters are required. In this project, a low cost reduced scale tire test machine will be developed to evaluate the longitudinal and lateral tire behavior. The generation of these tire forces based on the tire longitudinal slip, tire slip angle input and tire vertical force will be studied. The tire parameters determined using this machine could be used for simulation of reduced scale vehicles.

1.3 OBJECTIVE

1. To design and fabricate a reduced scale tire test machine which able to obtain one to fifth reduced scale tire parameter.
2. To perform stress analysis on the structure of the tire test machine.

1.4 SCOPE

1. Conduct literature study on the fundamentals of tire longitudinal and cornering stiffness.
2. Design a reduced scale tire test machine using CAD software.
3. Conduct stress analysis using CAE software.
4. Conduct fabrication to the tire test machine.

1.5 ORGANIZATION OF REPORT

The remaining sections in this report are presented in five chapters.

Chapter II:
This chapter included all study about tire, development of tire forces, previous development of scale model testing apparatus, full scale dynamics tire measuring device, advantages of reduce scale machine and theory of engineering design.

Chapter III:
This chapter discusses methodology used in this project by review generation of concept design, appropriate selection method for design evaluation and review of electronic components for machine installation. This chapter also explains all detail design by configure bill of mechanical components, bill of electronic component and identify suitable electric circuit and programming for the machine. Besides, this session also included stress analysis and development of Dugoff tire model for validation and explains the reduce scale tire test machine to carry out test to determine tire longitudinal stiffness and cornering stiffness.

Chapter IV:
This chapter review all the fabrication work had been done and all problems encounter during the machine development.

Chapter V:
This chapter summarizes important issue throughout the entire project and declares the function of the machine with recommendation for future work.

CHAPTER II

LITERATURE REVIEW

2.1 TIRE FORCES

Tire test machine is greatly related to development of tire forces and it behavior. The vehicle tire forces and moments from the road act on each tire contribute to the behavior of the tire. The tire receives force from the road is assumed to be at the center of the contact patch and can be decomposed along the three axes. The three axes is X- axis, Y-axis and Z-Axis. X-Axis due to longitudinal force F_x caused by vehicle longitudinal movement. Y-Axis due to the lateral force F_y cause by cornering effect and the force along the Z- axis due to vertical force F_z due to the vertical load support by the tire. Figure 2.1 shows the tire forces in three axes.

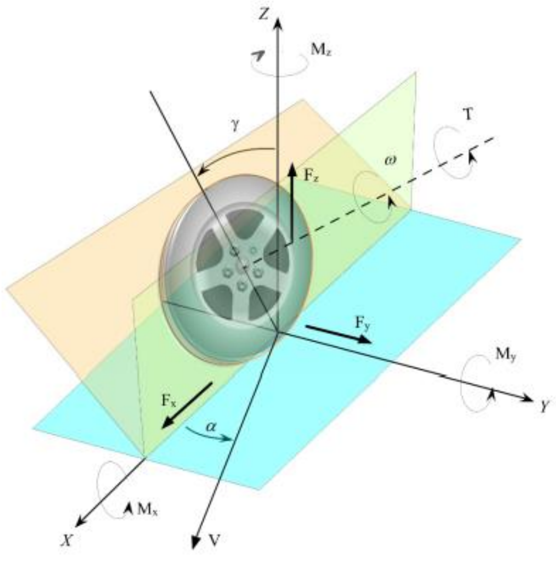

Figure 2.1: Tire forces in three axes

(Source: Rajamani, 2012)

2.1.1 Longitudinal Tire Force with Slip Ratio

Longitudinal tire force generated by tire depends on the slip ratio, the friction coefficient of the road surface and the normal force on the tire. If the friction coefficient of the tire-road interface is assumed to be 1 and the normal force is assumed to be a constant, longitudinal tire force is directly proportional to the slip ratio. Therefore the longitudinal tire force be modeled as

$$F_x = C_\sigma \sigma_x \tag{1}$$

where C_σ = longitudinal stiffness and σ_x = longitudinal slip. Longitudinal stiffness is a constant property of the wheel and the equivalent rotational velocity of the wheel as shown in Figure 2.2. This means, longitudinal slip is equal to $r_{eff}w\text{-}V_{x.}$ Slip ratio is equal to the difference between the longitudinal velocity at the axle of the wheel and the equivalent rotational velocity of the wheel, over maximum value. For braking, the maximum value is longitudinal velocity. Slip ratio for acceleration have the rotational velocity of wheel as the denominator (Longoria et al., 2004)

Slip ratio during braking:

$$\sigma_x = \frac{r_{eff}\,\omega_W - V_x}{V_x} \tag{2}$$

Slip ratio during acceleration:

$$\sigma_x = \frac{r_{eff}\,\omega_W - V_x}{r_{eff}\,\omega_W} \tag{3}$$

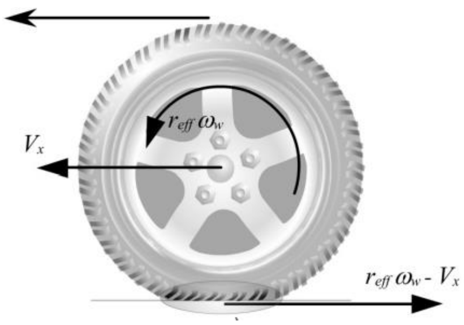

Figure 2.2: Diagram illustrates longitudinal velocity and rotational velocity of tire (Source: Rajamani, 2012)

2.1.2 Lateral Tire Forces

The lateral force on a tire is proportional to the slip angle at the tire. Therefore lateral force can be modeled as

$$F_y = C_\sigma(\delta - \theta_v) \tag{4}$$

where C_σ = cornering stiffness, δ = steer angle, θ_v = tire velocity angle and $\delta - \theta_v$ = the slip angle of a tire is the angle between the orientation of the tire and the orientation of the velocity vector of the wheel as shown in Figure 2.3. When a vehicle is traveling straight and not being steered, the velocity angle at the tire and the steering angle are both zero, resulting in zero slip angle. Obviously, the lateral tire force is proportional to slip angle. In the static region of the contact patch, the tip of each tread is in contact with the ground and remains stationary. The top of the tread therefore moves with respect to the tip of the tread resulting in tread deformation. The magnitude of lateral deflection of the tread is proportional both to the lateral velocity and to the magnitude of time spent by the tread in the contact patch. Since the lateral velocity is proportional to velocity and slip angle while the amount of time in the contact patch is inversely proportional to the rotational velocity, the lateral tread deflection is effectively proportional only to the slip angle. The lateral force on the tire based on the magnitude of lateral deflection of the treads in the contact patch. Hence, the lateral force is proportional to slip angle (Ertas et al., 1996)

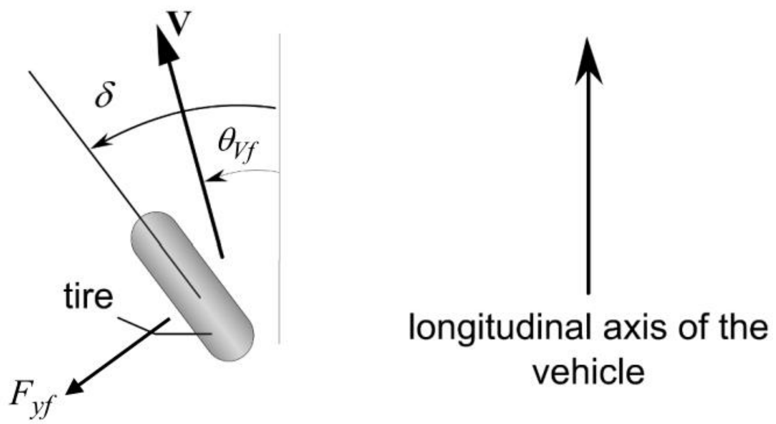

Figure 2.3: Slip angle and lateral force

(Source: Rajamani, 2012)