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Date : 12-5-2008

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Supervisor's Name 2 : .....
Date : .....

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# FINITE ELEMENT MODELING, ANALYSIS AND SIMULATION OF WIDE RIM ALLOY WHEELS

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The PSM (Projek Sarjana Muda) report is considered as one of the essential for students to complete their bachelor program in Mechanical (Automotive)

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MAY 2008

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"I admit that this report is my own work accept as in cited references"

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## ABSTRACT

In the current development of wheel manufacturing for the automotive industry, the standard wheel is mostly made of steel and light alloy wheel. The light alloy wheel can be perforated to save weight, achieve better brake cooling and recently alloy wheels are becoming increasingly popular the vehicle users. The main objective of the project is develop Finite Element model of wide rim alloy and analyze the phenomenon and wheel reaction due to radial load and inflation of tire air pressure. This research will analyze the safety aspect of wide rim alloy due cause by radial load occurs during driving a car. In this project, Finite Element Method (FEM) will be used in order to make the analysis, simulation and modeling of wide rim alloy. The method will be used to predict the maximum displacement and stress on the wheel under the specified load.. In this case, the CATIA software will be used to create 3D model of wide rim alloy .Finally, MSC NASTRAN and PATRAN software will be used to analyses and make simulation to gett the final result

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# ABSTRAK

Pada era globalisasi, pembuatan rim untuk industri automotif uga mengalami pembangunan anfd perkembangan. Kebanyakan rim diperbuat daripada besi dan aloi yang ringan dan rim aloi yang ringan ini mudah untuk ditebuk lubang untuk mengurangkan berat selain dapat mencapai tahap penyejukan brek yang lebih baik. Kebelakangan ini ,pengunaan rim aloi telah menjadi semakin popular dikalangan penguna kenderaan. Justuru objektif penyelidikan yang dijalankan ini lebih menjurus kepada penyelidikan rim aloi untuk menlihat fenomena dan reaksi rim tersebut apabila dikena tekanan jejarian serta kesan pengaruh pengembungan tekanan angin di dalam tayar ..Penyelidikan ini akan menganalisis rim aloi dari aspek keselamatan yang disebabkan oleh tekanan jejari ketika sedang memandu. Dalam penyelidikan ini, keadah elemen terhingga akan digunakan untuk memudahkan analisis dan simulasi model rim aloi. Kaedah ini juga akan digunakan untuk meramalkan di mana lokasi perubahan dan terikan yang tertinggi.. Dalam kes ini model rim akan direkabentuk melalui dengan mengunakan perisian CATIA. Perisian ini akan digunakan untuk membentuk gambaran 3 dimensi sebuah rim aloi..Seterusnya perisian MSC Nastran and MSC Patran akan digunakan untuk menganalisis dan simulasi unuk mendapatkan jawapan.

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# LIST OF SYMBOLS

$Q$ = radial load ($kgms^{-2}$)

$Sr$ = acceleration test factor

$Fr$ = maximum load on the tire, $kgms^{-2}$

$Wr$ = distributed pressure, $kg/ms^2$

$W_0$ = origin pressure, $kg/ms^2$

$r_b$ = the radius ,m

$b$ = width of the bead seat, m

$\theta_0$ = the angle of loading, radian

$Fp$ = axial component of the force, N

$P_0$ = the inflation pressure in the tire, $kg/ms^2$

$a$ = the design radius, m

$r_f$ = the radius of the loading point on the rim flange, m

$T_f$ = load on a unit length of the circumference of the rim flange of the rotating wheel, N

G = Shear Modulus, GPa

Nu = Poisson's ratio

E = Elastic Modulus Young, GPa

F= Forces cause by inflation air pressure in tire,N

q = load on a unit length of the circumference of the rim flange, N/m

L = distance between each node, m

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# CHAPTER 1

# INTRODUCTION

This chapter consist the objective and the scope of the project. It also includes the introduction to finite element method and automotive rim. Under the implementation wheel nowadays, there are also some discussions of problem statement affected to the wheel

## 1.1 Overview

This research is focuses on the modeling, analysis of wide rim alloy wheels using Finite Element Method (FEM). The FEM is a way of getting a numerical solution to specific problems. A FE analysis does not produce a formula as a solution, nor does it solve a class of problems. According to Robert D Cook (1995), the solution is approximate unless the problem is so simple that a convenient exact formula is already available. An unsophisticated description of the FE method is the FE method involves cutting a structure into several elements (pieces of the structure), describing the behavior of each element in a simple way, and then reconnecting elements at nodes as if nodes were pins of glue that hold element together. A more sophisticated description of FE method regards it as piecewise polynomial interpolation. That means in over an elements, a field quantity such as displacement is interpolated from values of the field quantity at nodes. By connecting elements together, the field quantity becomes interpolated over the entire structure in piecewise fashion .The best values of the field quantity at nodes are those that

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minimize some function such as total energy. The FE method was developed by engineers using physical insight than mathematicians using abstract methods. It was first applied to problems of stress analysis and has since been applied to other problem of continua. In all applications the analyst seeks to calculate a field quantity .In stress analysis, field quantity is the displacement field or `the stress field. Results of greatest interest are usually peak values of either the field quantity or its gradients.

Finite Element analysis is a simulation tools that enables engineers to simulate the behavior of a structure. Finite Element analysis is an important part of the overall design process, serving to verify a design prior to its manufacture. In finite element analysis, the design is subdivided into a series of element that are connected by nodes. Material properties and element properties are specified to represent the physical properties of the model. Boundary conditions and applied loads are then defined to represent the operating environment for which the design is to be subjected. As the analyst, the choices of element types and number of nodes are depend to us. It is important to realize that our results are accuracy. The ability of our results is depend on the proper choices of material properties, boundary conditions and applied loads.

Automotive wheels have in the time period spanning the last five decades progressively evolved starting with the early spoke designs of wood and steel, the carryovers from wagon and bicycle technology, flat steel disks, and more recently stamped metal configurations. The metal configurations in the present and newer generation of ground vehicles are made from cast aluminum alloys either in the as-cast or as cast plus forged condition. Historically, successful design was arrived at after years of experience coupled with extensive field testing. Since the 1970s several innovative methods of testing and experimental stress measurements have been developed and tried. During the most recent decade, the procedures have significantly improved by the emergence of a variety of experimental and analytical methods for structural analysis. Durability analyses, that is, fatigue life prediction and reliability methods, for dealing with variations inherent in engineering structures have been used for the study of automotive rims .Today, nearly all ground vehicles use wheels. These wheels have to support the weight of the vehicle, cushion the vehicle over surface irregularities, provide sufficient traction for driving and braking,

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and provide steering control and direction stability. The wide rim alloy can be categorizes as 3D solid. The 3D solid is used to mean a three dimensional solid that is unrestricted as to shape, loading, material properties and boundary conditions. There are six possible stress (three normal and three shear) must be analyze in 3D solid. Problems of beam bending, plane stress, plates can be regarded as special cases of 3D solid.

## 1.2 Background

This research will analyze the phenomenon of the wide rim wheels due radial load occur during driving and influence of inflation air pressure in the tire. The Finite Element Methods (FEM) will be used to predict maximum displacement and stress of the wheel under specific loads. The CATIA software will be used to produce the model or CAD data for the wheel rim car alloy with diameter of 18 inches. Then this CAD data will be employed into the MSC NASTRAN. This NASTRAN software will be used to analyze and simulate the crack or fracture. This research also purposes to assemble a comprehensive set of modeling, analysis and simulation of the wheel.

This project involves simulation and analytical investigation of wide rim car alloy with diameter18 inches. Since the failures are believed due to fatigue behaviors, an approach of fatigue failure is used. This criterion can determine the performance of the component at certain cyclic loading. The analytical or mathematical approach is used to obtain the fatigue failure and fracture mechanics criteria.

The calculated data is then entered in the computer for finite element analysis. CATIA analysis is used because it is supported with 3D part with an unlimited element and the illustration of stress distribution more clearly and stress at certain nodes can be obtained.

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## 1.3 Objective

The main aim of this research is to analyze the phenomenon of the wheel rim due to the radial loads and influence of inflation air pressure in the tire. Radial load is the best features in this project because it will definitely show how the wheel rim alloy condition reacts with the force given clearly. It is hoped that by performing this project, few justifications could be make on the wide rim alloy failure phenomenon. On the other hand, this research also purpose to present and discuss the conjoint influence of inflation pressure and radial load on stress and concomitant displacement distribution in the rim of a rotating body wheel such as the location of maximum and minimum displacement or stress. Besides this research results hopefully can be used by the Road Authority to test the wheels from any manufacturer before issuing certificate prior to marketing of the wheels.

## 1.4 Problem statement

In this globalization era, many car alloy wheels are available in the market with various diameters starting from 10” to 26” in diameter. This research wills using of wide rim alloy wheels was widely spread in our society especially for the young drivers. Most of our young drivers simply convert the standard rim wheels which are designed to the specific vehicle model into the rim wheels which are wider and more eye-catching. Wheels can be looked upon as safety-related components. Consequently, fatigue performance and state of stress distribution in the rim, under various loading conditions, is a subject of concerns. In this case changing the rim wheel with the new which are more wider in diameter may risk injury and accidents due to the change of load characteristics.

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## 1.5 Scope

The main idea of this research is to modeling, analysis and simulation of wide rim car alloy using FEM. Car alloy wheel available in the market now have different diameter starting from 10 inches until 26 inches. Initially this research are focuses on the wide rim wheels with 24 inches to 26 inches but unfortunately the rim 24 to 26 inches are not available in Malaysia market because the maximum diameter of wheel rim available in Malaysia is 22 inches .Therefore this research now is focuses on wheel rim car alloy with diameter of 18 inches. Besides the other scope of this research are finite element modeling, analysis and simulation.

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# CHAPTER 2

# LITERATURE REVIEW

This chapter will review about the history of vehicle wheel rim, type of rim, material, overview of Finite Element Method and overview of previous research about wheel rim

## 2.1 Introduction Of Vehicle Rim/Wheel

In the millennium era, transportation has been developed very fast and vehicle consumption has been part of our daily life. Wheel, tire and rim are one of important component inside the vehicles. Tire are differentiated according to the loads to be carried, the possible maximum speed of the vehicle, and whether a tube or tubeless is driven. The tire works as a wheel only after it is installed on the rim and is inflated. Therefore, the tire and wheel assembly influences the function and the performance of the vehicle. The tire is designed and manufactured to suit a standard rim and once installed on the correct rim the tire will perform up to its desired level. It is needless to say that the life of the tire will be shortened if it is installed on an unsuitable rim.

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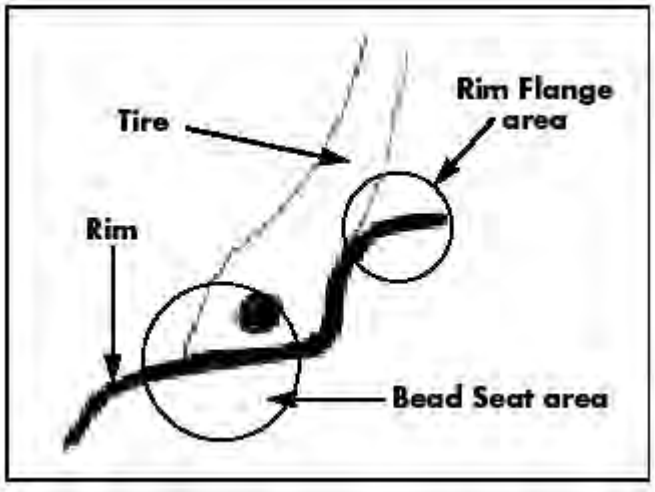


Figure 2.1 : The position of tire and rim(sources: Heyes Lemmerz (1986))

2.1.1 History of Wheel/Rim

The history of wheel was began when the human race starting to use the log to transport heavy objects. The original of the wheel were the round slices of a log and it was gradually re-in forced and used in this form for centuries on both carts and wagons.

This solid disc changed to a design having several spokes radially arranged to support he outer part of the wheel keeping it equidistant from the wheel centre.

A wooden wheel which used hard wood stakes as spokes was very popular as a wheel for many vehicles up to about 1920. Afterwards the disc wheel, in which the spokes were replaced with a disc made of steel plate, was introduced and is still being used to this day. Furthermore, a light alloy has come to be used currently as a wheel material for many types of vehicle.

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2.1.2 Type of Wheel/Rim (Dimensional)

The rim used for vehicles is provided are rely on each countries standard. This international standard, similar to tires, provides for a basic dimension for the rim diameter, width, and the flange shape, and others and is normal to every country in the world.

Recently the shape of the rim has settled to 5 degree Drop Center Rim to provide for international harmony.

a) Shape of rim

There are three types of typical rim shape vehicles are made up

i) Drop Center Rim (DC )

Drop Center Rim is shaped into a well between the bead seat parts which is located on both sides of the rim. This well is to make the mounting and dismounting of the tire easy. In most cases there is a taper of 5 degrees in the bead seat area.

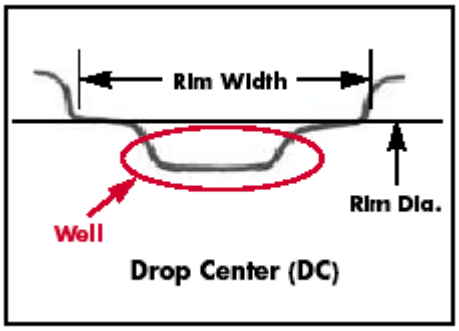


Figure 2.2 : Drop center Rim

(sources: www.toyojapan.com/tires/pdf/TTT_12.pdf)

ii) Wide Drop Center Rim ( WDCR )

Wide drop center rim is basically the same as DC Rim. In order to expand the width of the rim, the well is created shallower and the height of flange is reduced. This design is currently applied to rims for tires of most passenger vehicles.

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iii) Wide Drop Center Rim with hump ( WDCR-WH )

In addition, this design has a bump, which is called a hump, on the beginning of the bead seat area. This hump is to prevent the bead slipping down and air leakage from the rim due to the horizontal force applied to the tire when a vehicle tubeless tires turns at high speed.

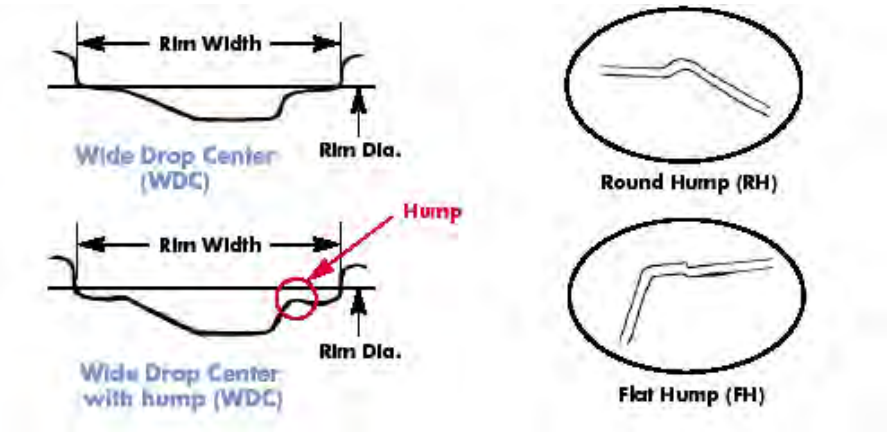


Figure 2.3: The different between wide drop center (WDC) and wide drop center with hump (sources: www.toyojapan.com/tires/pdf/TTT_12.pdf)

b) Rim Size Designation

Rim size designation is as below;


Figure 2.4: Rim size designation

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c) Rim Nomenclature

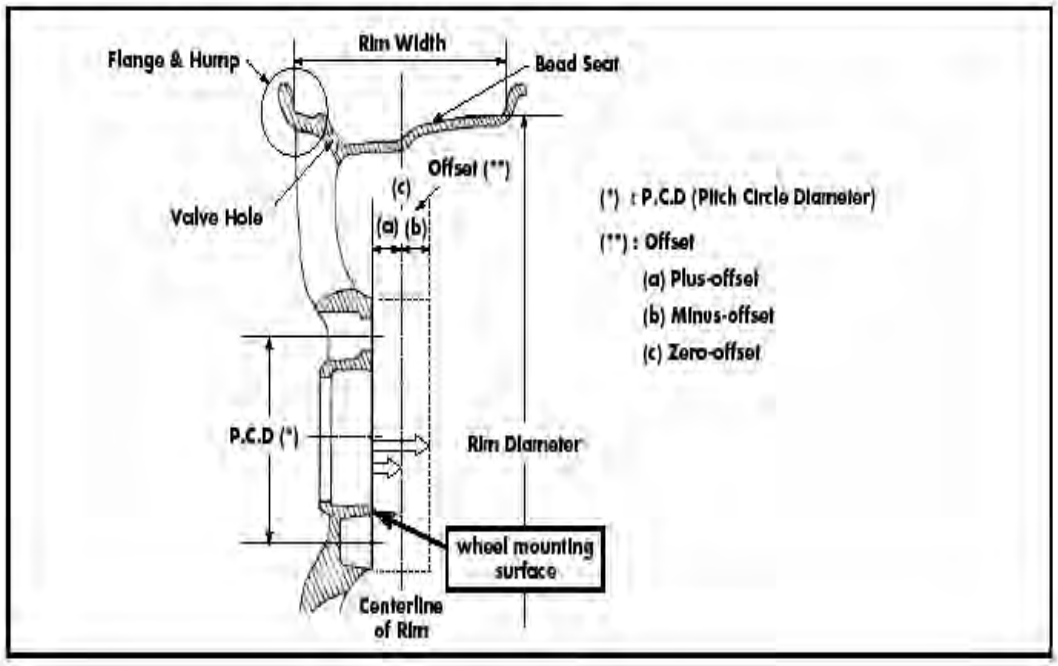


Figure 2.5: Rim Nomenclature ( sources: A. Currie, B.Wilson (1981))

i) **Wheel -** Wheel is generally composed of rim and disc.

ii) **Rim -** This is a part where the tire is installed.

iii) **Disc -** This is a part of the rim where it is fixed to the axle hub.

iv) **Offset -** This is a distance between wheel mounting surface where it is bolted to hub and the centerline of rim.

v) **Flange:** The flange is a part of rim which holds the both beads of the tire.

vi) **Bead Seat:** Bead seat comes in contact with the bead face and is a part of rim which holds the tire in a radial direction.

vii) **Hump:** It is bump what was put on the bead seat for the bead to prevent the tire from sliding off the rim while the vehicle is moving.

viii) **Well:** This is a part of rim with depth and width to facilitate tire mounting and removal from the rim.

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