Modal Analysis of Aluminium Alloy Five Spokes Wheel's Rim

HTAY HTAY WIN[1], MAY ZON THAN OO[2]
1, 2 Department of Mechanical Engineering, Mandalay Technological University

Abstract- This paper presents the modal analysis of car's wheel rim of Aluminium Alloy under the value of speed 100km/h. The model of wheel rim is drawn by using SolidWorks 2014 and analysed by ANSYS 14.5. The wheel rim is P205/75R*15. There are many forces acting on the wheel rim. Inflation pressure acts on the rim at 241kPa. Principal stress theory, von- Mises stress theory, deformation and natural frequency equations are applied by theoretically and numerically. The results from theoretical and numerical approaches of frequency of wheel's rim are compared. Working frequency of wheel's rim is 150.9876 Hz. Working frequency does not match with natural frequencies of wheel's rim at tenth mode shapes. Therefore, the wheel's rim has no tendency of resonance.

Indexed Terms- Car's Wheel Rim, Speeds, Stress, Deformation, Frequency

I. INTRODUCTION

The wheel is a device that there are forces acting on the car. Early wheels were simple wooden disks with a hole for the axle. The spoke wheel was invented more recently, and allowed the construction of lighter and swifter vehicles. Alloy wheels are automotive wheels which are made from an alloy of aluminium or magnesium or sometimes alloy steel.

Alloy wheels differ from normal steel wheels because of their lighter weight, which improves the steering and the speed of the vehicle. Spoked wheels of car are efficient, highly evolved, structural systems. To install the wheel, the holes in the centre section of the rim are placed over the studs and lug nuts are threaded onto the studs. The lug nuts can be tightened in across or star pattern. The tapered end of each lug nut matches a tapered area in the wheel mounting hole. The matching tapers help centre the wheel.

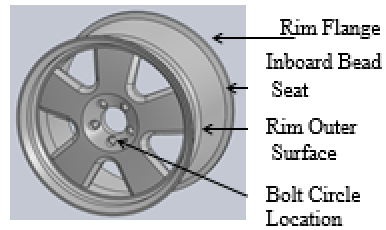

Fig 1. Car's Wheel Rim

On most steel wheels, the lug nuts can be tightened by hand or with an impact wrench. The lug nuts must be tightened to a specific torque [14].

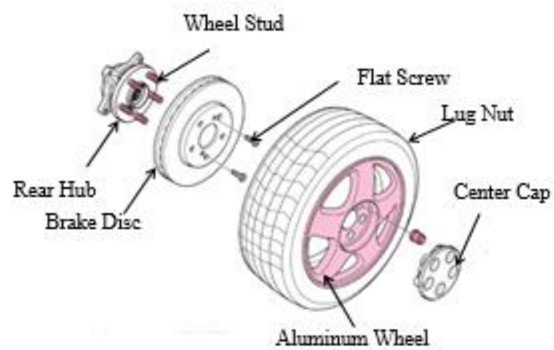

Fig 2. Aluminium Wheel is fastened to the Rear Hub with Steel Studs and Lug Nuts [16]

Figure 1 shows car's wheel rim. Figure 2 illustrates Aluminium wheel is fastened to the rear hub with steel studs and lug nuts.

II. FORCES ACTING ON THE CAR'S TYRE

Braking force, aerodynamic drag force, centrifugal force, friction force and tangential force act as x direction of car's wheel. Bump force, aerodynamic lift force and radial force act in the vertical direction as y of car's wheel. Lateral force and axial force act in the direction as z of car's wheel.

i. Vertical Weight, W_V

The total vertical weight is determined by the sum of the vehicle weight, passenger weight and extra weight. Vertical weight=vehicle weight+ passenger weight+ extra weight

ii. Lateral Force, F_L

Lateral force acts upon the wheel when steering or when there is a crosswind. They cause the vehicle to change direction.

$$F_L = [(C_f+C_r)\beta] + \frac{1}{v}(aC_f-bC_r)\omega-(C_f\delta) \quad (1)$$

iii. Braking Force, F_B

While the car is running with a constant speed, brake can be used to stop suddenly. Braking force appears at the time of one second and final speed is zero.

The braking time is the total time required to stop the vehicle absolutely.

$$F_B = ma = m\left(\frac{v_f - v_0}{t}\right) \quad (2)$$

iv. Friction Force, F_R

When braking force is applied to the wheel, frictional force is generated between the tire and the road surface. Coefficient of friction value depends upon the road condition and the weather conditions.

$$F_R = \mu F_N \quad (3)$$

v. Aerodynamic Drag Force, F_D

The aerodynamic drag force is the product of the density of air, the drag coefficient, frontal cross-sectional area of car and the car's speed. The value of lift coefficient (C_L) and drag coefficient (C_D) depend upon styles of car such as sedan, coupe, fastback and station wagon. The value of C_L and C_D is chosen for station wagon.

$$F_D = \frac{1}{2}\rho A C_D v^2 \quad (4)$$

vi. Aerodynamic Lift Force, F_L

The aerodynamic lift force is the product of the density of air, the lift coefficient, bottom cross-sectional area of car and the car's speed.

$$F_L = \frac{1}{2}\rho A C_L v^2 \quad (5)$$

vii. Radial Force, F_R

When the car is in motion, the radial load becomes cyclic in nature with a continuous rotation of the wheel. Radial load depends upon rim's radius, the width of the bead seat, the angle of loading and the inflation pressure in tire.

$$F_R = 8br_{rim}\theta_0 \quad (6)$$

viii. Axial Force, F_a

The air pressure, acting against the sidewall of the Kluger's tire, generates a load, which is in the axial direction.

$$F_a = (r_t^2 - r_{rim}^2)\frac{P_0}{4r_{rim}} \quad (7)$$

ix. Bump Force, F_m

Bump force is the force between the passenger and passenger's seat of car.

$$F_m = \frac{mv^2}{r_{rim}} + mg \quad (8)$$

x. Tangential Force, F_T

Tangential force is a force that acts on a moving body in the direction of a tangent to the curved path of the body.

$$F_T = \frac{mv^2}{r}\sin\theta \quad (9)$$

xi. Centrifugal Force, F_c

A centrifugal force is a force , arising from the body's inertia, which appears to act on a body moving in a circular path and is directed away from the centre around which the body is moving. Table 1 shows the specification data for the tyre of P205/75R*15. Table 2 shows properties of rubber.

$$F_c = \frac{mv^2}{r_{rim}} \quad (10)$$

Table 1 Specification data of wheel rim

Design Parameter	symbol	value	Unit
Aspect Ratio	AR	75	mm
Diameter of rim	D_{rim}	381	mm
Tyre Diameter	D_t	688.5	mm
Overall width	w	80	mm
Inflation Pressure	P_o	241	kPa

Table 1 shows the specification data for the wheel rim of P205/75R*15.

Table 2 Properties of Materials

Properties	Aluminium Alloy 7075-T6
Density	2810kg/m^3
Young's Modulus	72GPa
Poisson Ratio	0.33
Yield Stress	505MPa

Table 2 shows property of aluminium alloy considered for wheel rim of various speeds.

III. THEORY OF WHEEL'S RIM

The x-axis is the intersection of the wheel plane and the road plane with positive direction forward. The y-axis perpendicular to the road plane with positive direction upward. The z-axis in the road plane, its direction being chosen to make the axis system orthogonal and right hand.

There are vertical component acting in the y direction, longitudinal component acting in the x direction, and lateral component acting in the z direction. The force exerted in the x direction is the sum of friction force, braking force, aerodynamic drag force and tangential force. The force exerted in the y direction is the sum of bump force, lift force and radial force. The force exerted in the z direction is the sum of lateral force, axial force and centrifugal force.

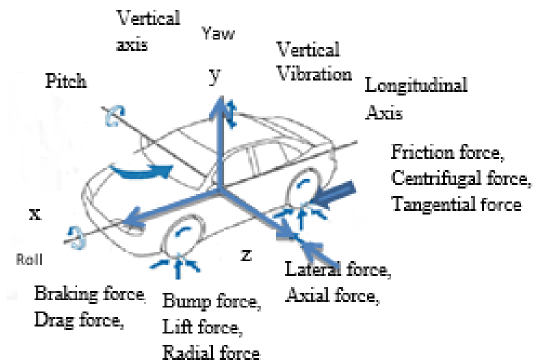

Fig 3. Forces Acting on the Car [1]

Figure 3 shows the forces acting on car direction of x, y and z.

Stress in x direction, $\sigma_x = \frac{F_x}{A_x}$ (11)

Stress in y direction, $\sigma_y = \frac{F_y}{A_y}$ (12)

Stress in z direction, $\sigma_z = \frac{F_z}{A_z}$ (13)

By using von-Mises Criterion equation,

$$\bar{\sigma} = \frac{1}{\sqrt{2}}\left[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2\right]^{\frac{1}{2}} \quad (14)$$

$$\text{Deformation, } \delta = \frac{Pl}{AE} = \frac{\sigma l}{E} \quad (15)$$

$$\text{Natural Frequency, } F(Hz) = \frac{1}{2\pi}\sqrt{\frac{g}{\delta}} \quad (16)$$

Effective stress, deformation and frequency can be calculated by using the equation 14, 15 and 16.

IV. MODAL ANALYSIS OF WHEEL'S RIM

In modal analysis of wheel's rim, only fixed support is provided at the bolt hole circle location of car's wheel as shown in figure 4. ANSYS software is used to analyse the ten mode shapes of wheel's rim.

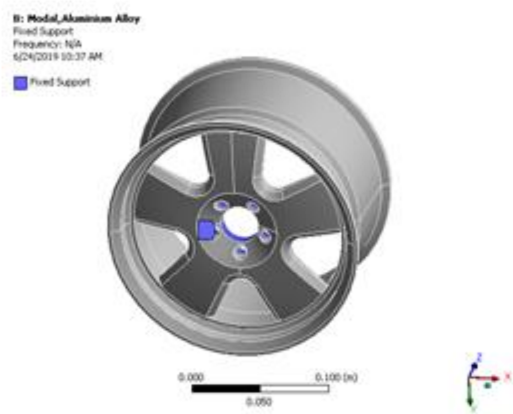

Fig 4. Fixed Support

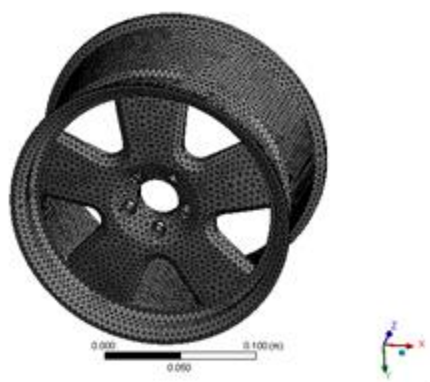

Fig 5. Meshing of Wheel's Rim

This geometry model was meshed with high smoothing of 11230 nodes and 1512 elements as shown in Figure 5. This meshed model was imported to static structural analysis.

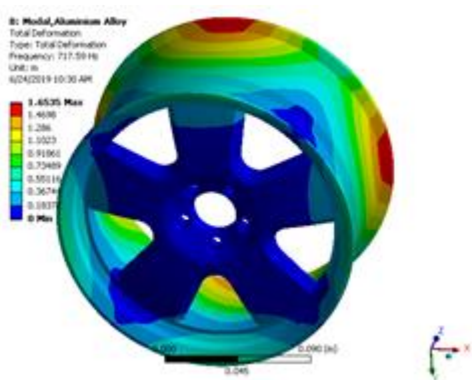

Fig 6. First Mode Shape of Wheel's Rim

The first mode shape of front wheel's rim is shown in Figure 6. Total deformation of first mode shape is 1.6535m at frequency 717.59 Hz.

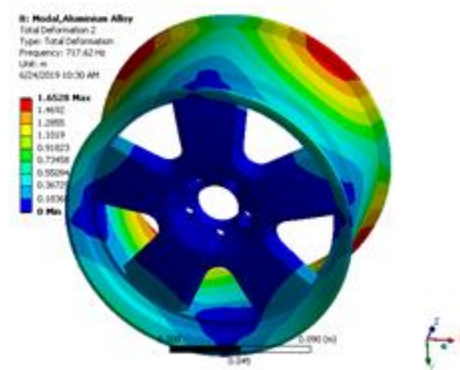

Fig 7. Second Mode Shape of Wheel's Rim

The second mode shape of wheel's rim is shown in Figure 7. Total deformation of second mode shape is 1.6528m at frequency 717.62 Hz.

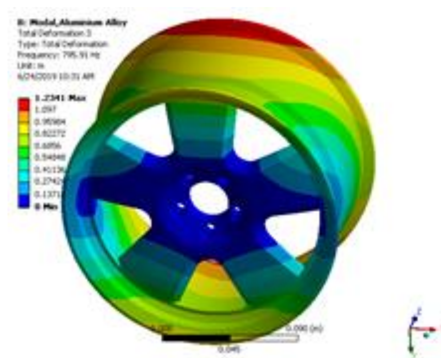

Fig 8. Third Mode Shape of Wheel's Rim

The third mode shape of wheel's rim is shown in Figure 8. Total deformation of third mode shape is 1.2341m at frequency 795.91 Hz.

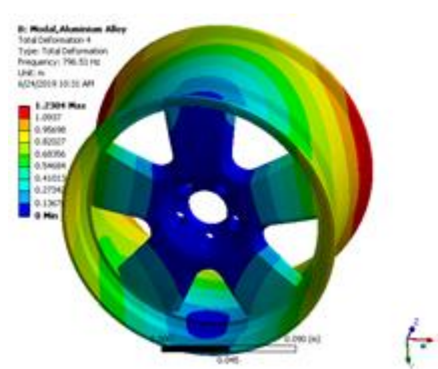

Fig 9. Fourth Mode Shape of Wheel's Rim

The fourth mode shape of wheel's rim is shown in Figure 9. Total deformation of fourth mode shape is 1.2304m at frequency 796.51 Hz.

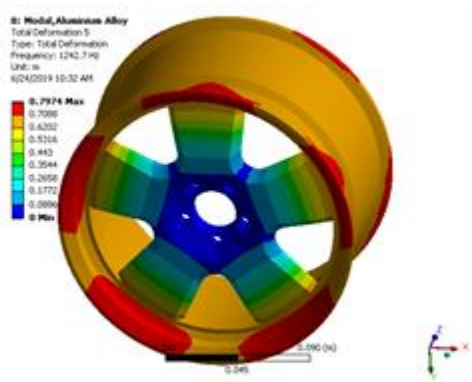

Fig 10. Fifth Mode Shape of Wheel's Rim

The fifth mode shape of wheel's rim is shown in Figure 10. Total deformation of fifth mode shape is 0.7974m at frequency 1242.7 Hz.

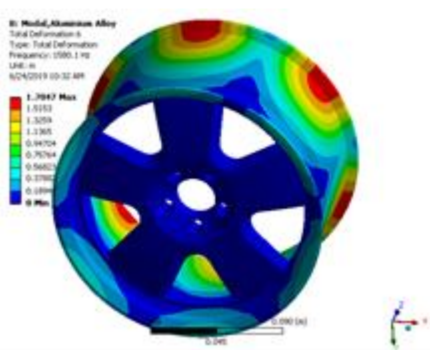

Fig 11. Sixth Mode Shape of Wheel's Rim

The sixth mode shape of wheel's rim is shown in Figure 11. Total deformation of sixth mode shape is 1.7047m at frequency 1580.1 Hz.

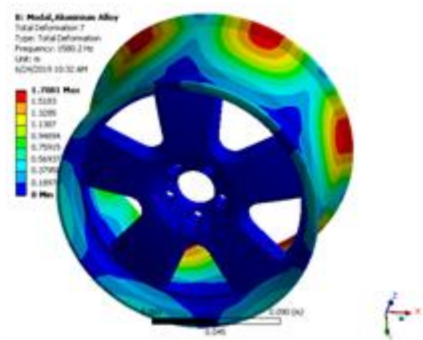

Fig 12. Seventh Mode Shape of Wheel's Rim

The seventh mode shape of wheel's rim is shown in Figure 12. Total deformation of seventh mode shape is 1.7081m at frequency 1580.2 Hz.

The eighth mode shape of wheel's rim is shown in Figure 13. Total deformation of eighth mode shape is 0.82588m at frequency 2168.6 Hz.

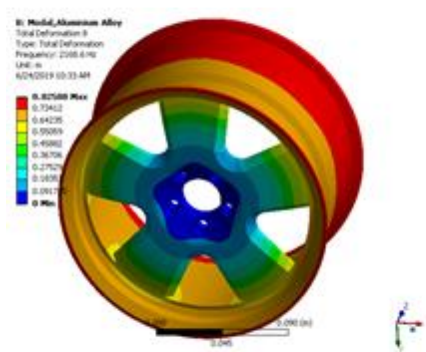

Fig 13. Eighth Mode Shape of Wheel's Rim

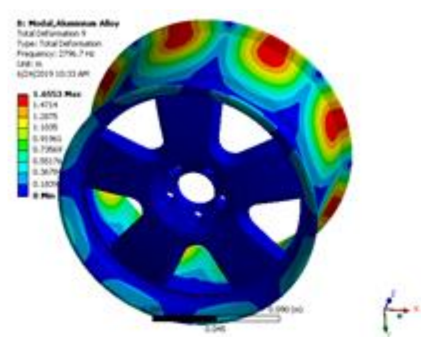

Fig 14. Ninth Mode Shape of Wheel's Rim

The ninth mode shape of wheel's rim is shown in Figure 14. Total deformation of ninth mode shape is 1.6558m at frequency 2796.7Hz.

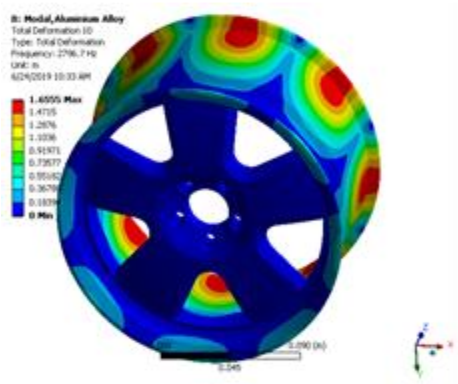

Fig 15. Tenth Mode Shape of Wheel's Rim

The tenth mode shape of wheel's rim is shown in Figure 15. Total deformation of tenth mode shape is 1.6555m at frequency 2796.7Hz.

The natural frequencies and mode shapes are important parameters in the design of a structure for dynamic loading conditions. The numerical results of natural frequencies for global mode shapes were compared with working frequency of wheel's rim. The natural frequencies at tenth mode shapes of wheel's rim are shown in Table.

Table 3. Natural frequencies of tenth mode shapes of wheel's rim

Mode	1	2	3	4	5
Frequencies (Hz)	718	718	796	797	1243

Mode	6	7	8	9	10
Frequencies (Hz)	1580	1580	2169	2797	2797

Table 3 shows natural frequencies of tenth mode shapes of wheel's rim. Working frequency of wheel's rim is 150.9876 Hz. Working frequency does not match with natural frequencies of wheel's rim at tenth mode shapes. Therefore, the wheel's rim has no tendency of resonance.

V. CONCLUSION

In this research, forces acting on the rim are calculated in the direction of x, y and z. Then, the stresses, deformation and natural frequency of the rim are calculated for materials aluminium alloy at speed 100km/h. The natural frequency is analysed by Ansys 14.5 at different speeds 100km/h. And theoretical results and numerical results of natural frequency are compared. From result, working frequency of wheel's rim is 150.9876 Hz. Working frequency does not match with natural frequencies of wheel's rim at tenth mode shapes. Therefore, the wheel's rim has no tendency of resonance.

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NOMENCLATURE

v -speed of car
β -slip angle of car
δ -steering angle
μ -coefficient of friction
C_D, C_L-Drag Coefficient and Lift Coefficient
r_{rim} -the radius of rim
r_t -radius of tire
P_0 -inflation pressure in tire
$\bar{\sigma}$ -Von-Mises stress
$\bar{\varepsilon}$ -equivalent elastic strain
δ -deformation
E - Modulus of elasticity

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