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Research Article

Analysis and Topological Optimization of Two-Wheeler Rear Wheel

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Abstract

This article is based on modification of a motorcycle component namely the rear wheel. The modification process is based on material and topology modification and validation using finite element analysis. The results obtained from modified analysis are compared with a rear wheel made with approximate dimensions in normally used wheels which we called original rim. The main aim is to reduce the mass of the components without much compromise in other factors. For analysis and study, a 150 cc motorcycle was selected as it is most common.

Keywords: *Front Wheel, topological modification and validation.*

1. Introduction

Any object requires energy for its movement in the atmosphere. Humans and other animals require energy for walking or running which is muscular energy. Vehicles are a medium of moving objects over considerable distances without use of muscular energy. But this requires other powerful energy source contained within the vehicle. This source could be an IC engine or electric motor depending on use. IC engine powered vehicles have a long history and are still dominant in its segment. These engines use fossil fuels mainly petroleum oils and gases as fuels having higher calorific values. Gasoline, diesel oils and natural gases are widely used on regular basis. These are being used continuously since a long time ago and continue to be explored. Although the development of new sources is in progress, there surely is a need to retard the demand of non-renewable energy sources. The process of burning gasoline to power cars and trucks contributes to air pollution by releasing a variety of emissions into the atmosphere. Emissions that are released directly into the atmosphere from the tailpipes of cars and trucks are the primary source of vehicular pollution. But motor vehicles also pollute the air during the processes of manufacturing, refueling, and from the emissions associated with oil refining and distribution of the fuel they burn. Primary pollution from motor vehicles is pollution that is emitted directly into the atmosphere, whereas secondary pollution results from chemical reactions between pollutants after they have been released into the air. India was the sixth largest motor vehicle/car manufacturer in the world in 2013. India is the second largest motorcycle (6.54 m produced in 2007-08) and the fourth largest commercial vehicle manufacturer in the world. This shows that motorcycles are major contributors to the overall vehicles. They share a large part of total daily fuel consumption of our country. An average human weighs about 65-75 kg. The combined weight of motorcycle and rider would be near about 200-220 kg. Hence we can say that about 70 % of fuel is consumed by the motorcycle itself. Obviously this cannot be eliminated nor can be drastically reduced but a slight reduction in one two-wheeler will cause a significant impact upon overall fuel consumed by the same model all over the country.

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2. Nomenclature

$\mathbf{R_N}$	Normal reaction on the wheel
S_{yt}	Yield Strength of the Material
σ_{all}	Allowable stress
N_f	Factor of Safety
$\mathbf{P_{Tmax}}$	Maximum tyre air pressure
Θ	Cornering angle
$\mathbf{I_f}$	Inertia of wheel
$\mathbf{P}$	Equivalent Bearing Load
T_e	Engine Torque
T_h	Torque on hub
N_s	Sprocket ratio
N_g	Gear ratio

3. Rear Wheel

Wheel is one of the most important components of an automobile. It supports and bears the entire vehicle load. It suffers not only the vertical force but also the irregular forces resulting from the car's ride, braking, cornering, road bumps, and all uneven shocks in the process of moving on road. Due to high speed rotation, its quality has a huge impact on wheel stability, handling and other characteristics. Wheels are clearly safety related components and hence fatigue performance and the state of stress in the rim under various loading conditions are prime concerns. Further, wheels continue to receive a considerable amount of attention as part of industry efforts to reduce weight through material substitution and down gauging (Mr. Sushant K. Bawne, *et al*, 2015). Although wheels are loaded in a complex manner and are highly stressed in the course of their rolling duty, light weight is one of the prime requirements, hence cast and forged aluminum alloys are essential in the design.

CAD modelling of the wheels was done using CATIA V5 software. A reverse engineering approach was used to model the wheels. The current wheel is being manufactured by casting. The original weight was 5.08 kg whereas the cad model weight showed 5.07 kg. Hence the accuracy of the model is 99.8%. This may not be totally justified as there is coating of some protective material such as paint.

4. Material modifications

Original material used was Al Alloy201.0-T43 Insulated. The material used in the modified wheel is Al 7075. It is used to increase the overall strength of the rim keeping an eye on the weight of material [9]. Aluminum is used instead of steel because it can withstand a lot of forces compared to the steel rims with the advantage being lower density compared to the steel rims. Following is the comparison of the previous material and the new material. Though the density of both the materials is same, al 7075 has higher strength which can be used as a scope for weight reduction by geometry modification.

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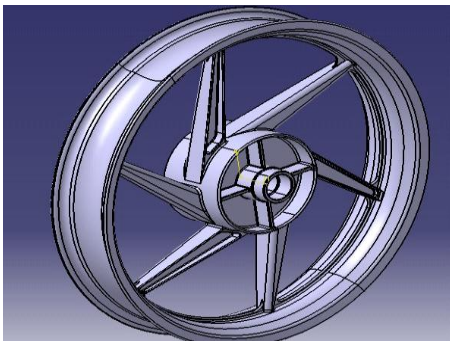
Table 1 Material comparison (Sanup K Panda, 2012)

Sr. No	Property	Al alloy 201.0-t43	al 7075
1	Elastic Modulus (GPa)	71	72
2	Poisson's ratio	0.33	0.33
3	Mass Density(kg/m^3)	2800	2800
4	Tensile Strength (MPa)	273	423
5	Yield Strength (MPa)	225	510

5. Geometry modifications

The original geometry was tested for stress distribution. The calculations then were used in modifying the rim for proper stress distribution with limiting the mass of the component. More scope was found for material reduction in the rim and hub portion. The hub portion was slotted since it was found to be quite safe in analysis. This contributed to weight reduction. The rim thickness was also reduced by 1mm (BGN Satya Prasad, *et al*, 2013). The rib portion was kept as it was since its modification would require changes in sprocket and it would not be compatible to the original model. Same case was with the brake drum cavity. The weight of modified rim is 4.5862 kg.



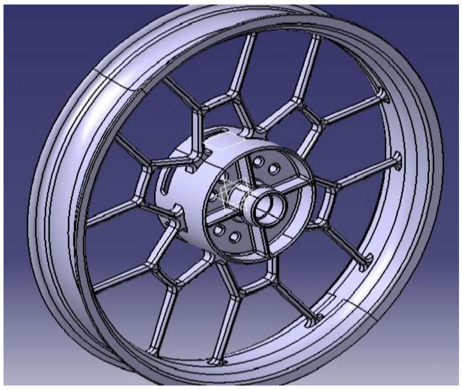


Fig.1 CAD models

6. Analysis

FEA analysis (K. Venkateswara Rao, *et al*, 2014) is performed on both original and modified front wheel model. Auto meshing was done using ANSYS workbench 15.0 software. Meshing used was auto mesh generated by ANSYS Workbench 15.0. The number of nodes were 125930 and elements were 67196.

6.1 Rear Wheel under Speed and Pressure

This is the simplest static condition when the wheel is running at normal or highest designated speed. Maximum rated tyre pressure along with normal reactions is applied.

Loads and boundary conditions- The motorcycle weight of 143 kg along with average occupants' weight of 150 kg was considered. Bearing load was applied to the center axle where bearings will be mounted. Out of the total load, 60% was distributed to the front wheel. Hence reaction at front wheel,

$R_N = 293 \times 0.6 \times 9.81 = 1760$ N.

Considering a maximum speed of 120 kmph *i.e.*33.33 m/s, the rotational speed for wheels is calculated as 148.35 rad/s

i.e. $\omega = 148.35$ rad/s.

The maximum rotational speed of 150 rad/s was applied for analysis purpose. Thus vertical reaction was applied as 1150 N approximately. Also the maximum permissible tyre pressure of 28 psi was used for the analysis *i.e.* P_{Tmax} = 32 psi. For the original wheel model, the bearings used were deep groove ball bearings with designation 6301LLUC3.

Assuming a standard bearing life of 50 million revolutions *i.e.* L_{10} = 50mR. For this bearing, Dynamic load capacity C = 9750 N ("Design of Machine elements" by V.B.Bhandari).

The equivalent bearing load is given by the formula,

$$P = \frac{C}{(L_{10})^{\wedge}0.3} \qquad (1)$$

Using this formula, the equivalent bearing load is calculated to be 3015 N in radial direction. Frictionless support is applied at the center and the wheel is constrained to move in the axial direction. The equivalent stress was found to be 89.803 MPa. The yield stress was 423 MPa. These values are quite low than allowable stress. Hence, giving F.O.S of 4.71. While doing research we found that on an average it should be above 1.5.

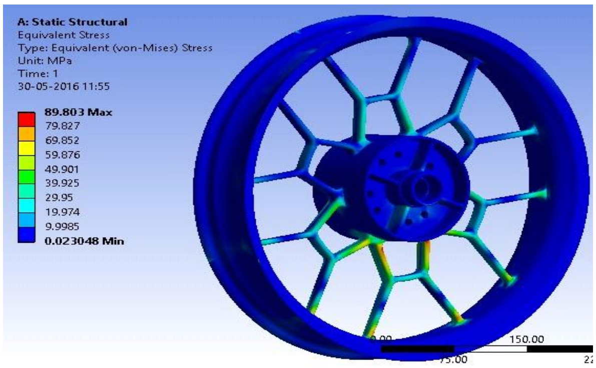


Fig.2 Equivalent Stress on Front Wheel under speed and pressure

6.2. Acceleration

During acceleration, the force from engine is transmitted from the engine sprocket to the chain in the form of tension (Madhu K S, *et al*, 2014).This chain tension is created into a moment a sprocket. The sprocket is engaged into the hub ribs. Hence, during acceleration, the ribs undergo shearing at an interface with the hub.

The rated torque of the two wheeler model is 12.5 Nm i.e. this torque is available on the engine shaft. Maximum torque will be available on the first gear. Following are the gearing ratios-

- I^{st} gear - 2.92
- II^{nd} gear - 1.88
- III^{rd} gear- 1.38
- IV^{th} gear – 1.08
- V^{th} gear–0.92

Also, the sprocket ratio is N_s = 2.933. Hence, the maximum torque available in the first gear at the hub can be calculated as below

$$T_h = (T_E \times N_{g1} \times N_s) \qquad (2)$$

i.e. 12.5 x 2.92 x 2.933 = 107055 Nm

This torque is applied with pressure and bearing load as earlier.

6.2.1. Rim free condition

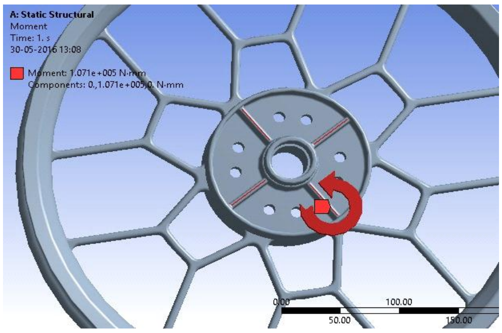


Fig.3 Application of moment

This condition acts as a simulation when accelerating on a plane road. The maximum shearing in ribs can be calculated in this condition. Boundary conditions – Bearing frictionless support was applied at the center and axial displacement was constructed. The maximum equivalent stress determined was 46.471 MPa. This shear stress is induced in the rib hub interface.

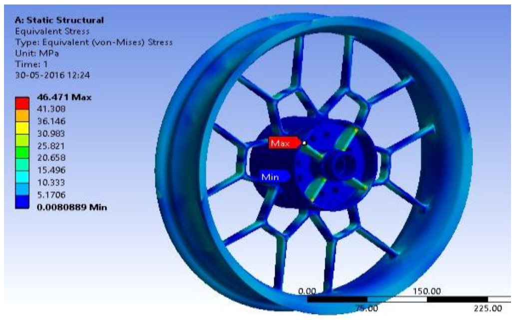


Fig.4 Equivalent Stress in rim free condition

6.2.2. Rim fix condition

This condition is applicable during bumpy rides on uneven roads or in case of heavy loading on bike like one during riding in uphill direction. In this condition, the spoke shearing is found to by fixing the rim and applying torque to the hub portion. Loads and boundary condition- Same rated torque was applied as in previous condition. The outer rim is fixed. Pressure and bearing load were same as earlier. Frictionless bearing support was applied at the center.

Fig.5 Fixing the rim

The maximum equivalent stress determined was 46.499 MPa. This shear stress is induced in the spokes. Comparing the original model and the new modified model stress are relatively comparable and are almost equal. The factor of safety of the original model was determined to be 7.24, while the modified factor of safety was derived to be 9.01.

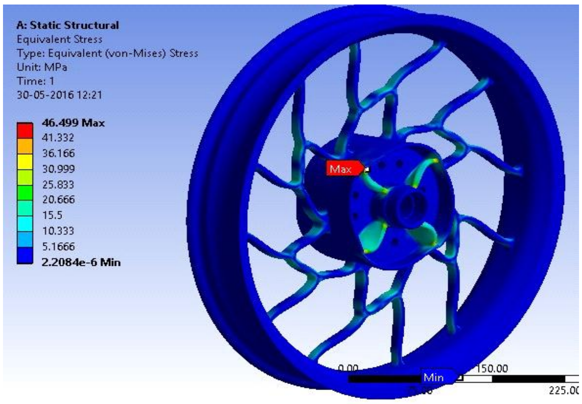


Fig.6 Equivalent stresses in rim fix condition

6.3. Cornering Condition

During cornering, lateral forces act on the wheel at the rim. This is due to the load transfer at the inner side.

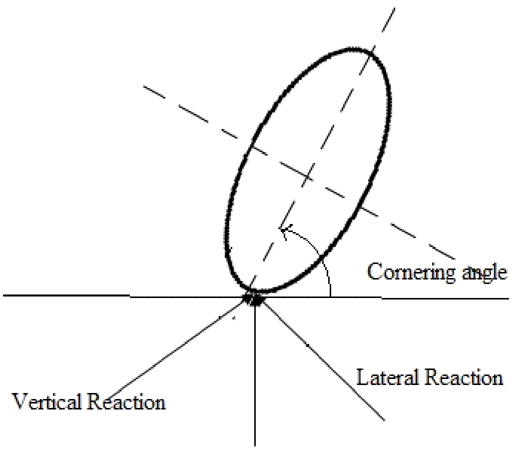


Fig.7 FBD during cornering

Considering 60 % of load on rear side and maximum cornering angle of $\theta = 45^0$ .Maximum static reaction is equal to R_N = 1901.18 N on rear wheel. During cornering it is split into mutually perpendicular components, the lateral component being $R_N \cos \theta$ *i.e.* 1901.18 Cos 45^0 = 1344.35 N. Hence we applied a lateral force of 1345 N. At maximum speed of ω = 150 radian/ second, the torque on rear hub is

$$T_h = (T_E \times N_{g5} \times N_S) \tag{3}$$

i.e. 12.5 x 0.92 x 2.92 = 33.58 Nm. (On fifth gear).Pressure, support and bearing load are same as earlier.

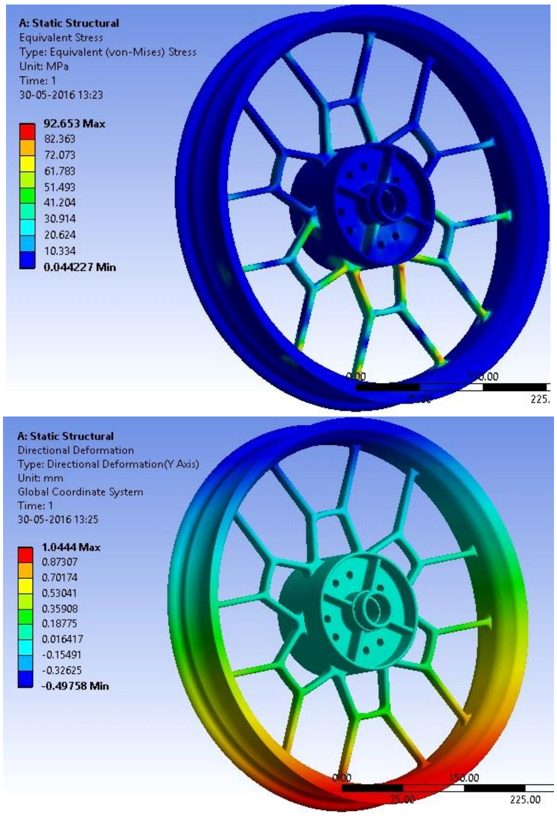


Fig.8 Deformation and stress due to cornering condition

The equivalent stress and deformation was found out to be 92.653 MPa and 1.044 mm respectively. The original values were 86.218 MPa and 0.5 mm respectively. Thus there is small increase in stress and deformation but wheel is quite safe.

6.4. Modal Analysis

Modal analysis is performed to find the natural frequency and mode shapes for the wheel model. For safe working, all the mode frequencies should exceed the actual encountered frequency. Similar to front wheel, the safe working frequency should exceed 21.78 Hz. Hence we set a minimum frequency criterion of 50 Hz. Hence all the mode frequencies should exceed this value for safe and effective working (BGN Satya Prasad, *et al*, 2013).

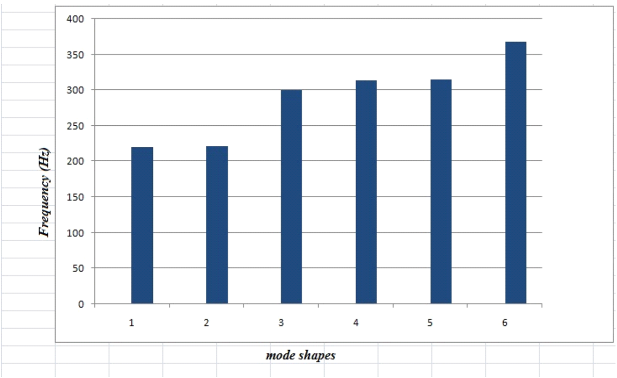


Fig .9 Mode frequencies for original wheel

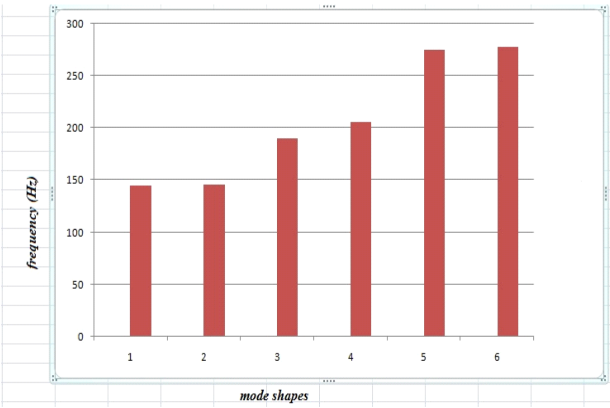


Fig. 10 Mode frequencies for modified wheel

From above graphs we can conclude that though the natural frequencies are less for modified wheel as compared to original wheel but they exceed the unsafe limit by a considerable margin.

6.5. Radial Fatigue Test

Aluminum wheels should not fail during service. Their strength and fatigue life are critical. In order to reduce costs, design for light-weight and limited-life is increasingly being used for all vehicle components. In the actual product development, the rotary fatigue test is used to detect the strength and fatigue life of the wheel. Therefore, a reliable design and test procedure is required to guarantee the service strength under operational conditions and full functioning of the wheel. Loads generated during the assembly may cause significant levels of stress in components. Under test conditions, these high levels of stress alter the mean stress level which in turn, alters the fatigue life and critical stress area of the components as well.

Fatigue strength of Al 7075(Liangmo Wang,*et al*, 2011): For analysis, high cycle fatigue criterion was used for wheel. The objective is to design the wheel for infinite life. The fatigue data of Al 7075 was obtained from. Following graph shows the material SN curve and simulation of radial fatigue test. A vertical force of 1300 N was added considering weight and overages. A rotational velocity of 150 rad/s was applied. Pressure and bearing load were applied as mentioned earlier. Bearing frictionless support was applied to hub (J. Janardhan,*et al*, 2014). Following graph depicts the stress life relation for the component.

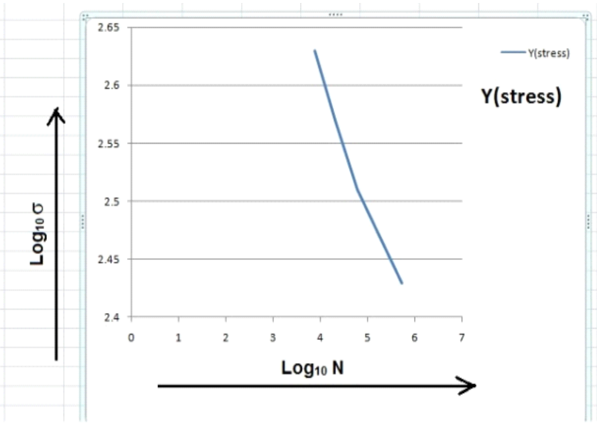


Fig.11 Al 7075 SN curve

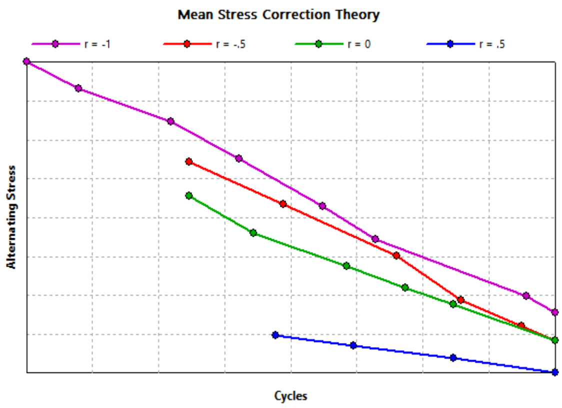
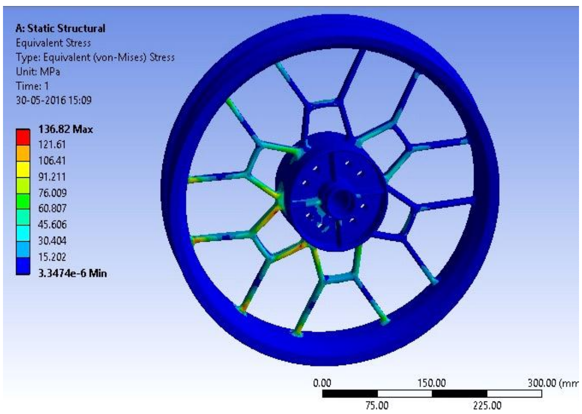


Fig 12 Component SN curve

The minimum safety factor was found to be 3 and minimum life was found to be 4.5927e5 cycles.

6.6 Impact Testing (Sivakrishna,*et al*, 2014)

Impact testing is necessary to ensure safe working of the wheel. For this reason an impact force of 6000 N was applied radially and 2000 N laterally.



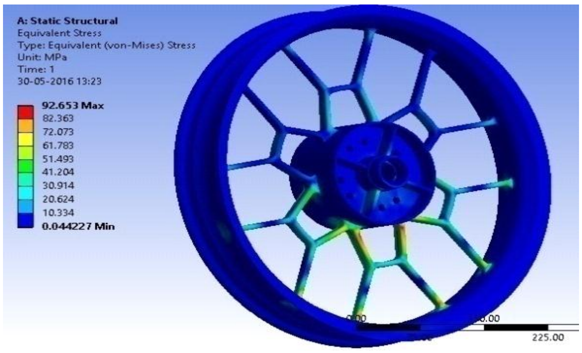


Fig. 13 Equivalent stresses in radial and lateral impact tests

Conclusions

For modified front wheel, the weight was found to be 4.56 kg whereas the original front wheel weighed 5.1kg. The stresses induced are found to be within limits. This shows that the above proposed design could be a good option as far as weight is concerned. Further study may be needed to investigate the manufacturing feasibility, although high pressure die casting seems suitable. Hence the overall weight reduction achieved was 10.6%.

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