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Structural evaluation of an automobile wheel

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Abstract---A wheel is a circular component that revolves on an axle and is fitted below the vehicle and enhances smooth movement of particles placed on the wheel. Wheels, in conjunction with axles, allow heavy objects to be moved easily facilitating movement or transportation while supporting a load, or performing labor in machines. Wheels are also used for other purposes, such as a ship's wheel, steering wheel, potter's wheel and flywheel. In our project the design and study of the structure of wheel with various factors and applying the load conditions and analysis using ansys software.

Keywords--- Design, analysis, structure of car wheel.

I. Introduction

The Common examples of wheels are found in transport applications. A wheel greatly reduces friction by facilitating motion by rolling together with the use of axles. In order for wheels to rotate, a moment needs to be applied to the wheel about its axis, either by way of gravity, or by the application of another external force or torque.

Components of wheel

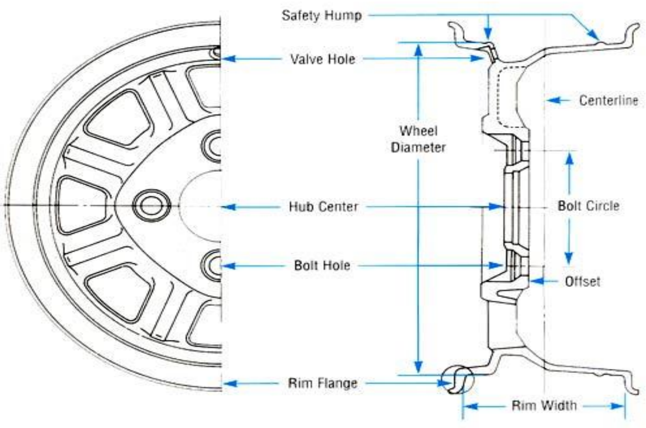

Fig.1 Structure of wheel

Hub: A hub is the center part of a wheel. It consists of an axle, bearings and a hub shell. The hub shell typically has two machined metal flanges to which spokes can be attached. Hub shells can be one-piece with press-in cartridge or free bearings or, in the case of older designs, the flanges may be affixed to a separate hub shell.

Fig.2 Hub

Axle: A rod or spindle (either fixed or rotating) passing through the centre of a wheel or group of wheels.

Fig.3 Axle

Rim: The rim is commonly a metal extrusion that is butted into itself to form a hoop, though may also be a structure of carbon fiber composite, and was historically made of wood. Some wheels use both an aerodynamic carbon hoop bonded to an aluminum rim on which to mount conventional bicycle tires. Metallic bicycle rims are now normally made of aluminium alloy.

Tyre: The wheel's outer covering is called the tire. Typically made out of rubber, tires provide cushioned support for the weight of the car, traction control for moving and stopping, along with a replaceable barrier between rim and road.

Fig.4 Rim of a Wheel

Fig.5 Tyre of a Wheel

Spokes: The rim is connected to the hub by several spokes under tension.One end of each spoke is threaded for a specialized nut, called a nipple, which is used to connect the spoke to the rim and adjust the tension in the spoke. This is normally at the rim end.

Fig.6 Spokes of a Wheel

Alloy wheels: wheels are those wheelsthat are made from an alloy of aluminium or magnesium, and are mixtures of a metal and other elements. They generally provide greater strength over pure metals, which are usually much softer and more ductile. Alloys of aluminium or magnesium are typically lighter for the same strength, provide better heat conduction, and often produce improved cosmetic appearance over steel wheels. Although steel, the most common material used in wheel production, is an alloy of iron and carbon, the term "alloy wheel" is usually reserved for wheels made from non ferrous alloys.

The earliest light-alloy wheels were made of magnesium alloys. Although they lost favor for common vehicles, they remained popular through the 1960s, albeit in very limited numbers. In the mid to late 1960s, aluminum-casting refinement allowed the manufacture of wheels that were safe. Until this time, most aluminum wheels suffered from low ductility, usually ranging from 2-3% elongation. This meant these earlier aluminum-alloy wheels were quite brittle. Because light-alloy wheels at the time that were often made of magnesium (often referred to as "mags"), these early wheel failures were later attributed to magnesium's low ductility, when in many instances these wheels were poorly cast aluminum alloy wheels. Once these aluminum casting improvements were more widely adopted, the aluminum wheel took the place of magnesium as low cost, high-performance wheels for motorsports.

Fig.7 Alloy wheel of an automobile

Characteristics

Lighter wheels can improve handling by reducing unsprung mass, allowing suspension to follow the terrain more closely and thus improves grip, however not all alloy wheel are lighter than their steel equivalents. Reduction in over-all vehicle mass can also help to reduce fuelconsumption.Better heat conduction can help dissipate heat from the brakes, which improves braking performance in more demanding driving conditions and reduces the chance of reduced brake performance or even failure due to overheating.

Fig.8 An aluminum alloy wheel designed to recall the crossed spokes of a wire wheel

II. Manufacturing

Aluminium penetration in wheels was in the year 2000 for European vehicles about 30 to 35%, compared to largely more than 50% in USA and Japan. This is representing more than 14% of the average aluminum content of a vehicle and is expected to +rapidly increase (foreseen 45% in 2005 and 70% in 2010). In the US, the repartition of aluminium in wheels was in the year 1999:82% cast, 11% forged (including all vehicles), 4% for sheet and 3% for plate. In Europe, the share of casting is slightly higher (more than 85%) due to the lesser extent of forged wheels for trucks (including light ones). However many developments are on the way to reduce weight of present aluminum wheels without fully sacrificing style. With this purpose, a really attractive compromise could consist in cast central discs (or forged when competitive), assembled (mainly by welding) to extruded or laminated rims.

III. Bolt design:

The bolt pattern determines the number and position of the mounting holes to allow the wheel to be bolted to the hub. As the bolts are evenly spaced, the number of bolts determines the pattern. For ex: smaller cars have three (Citroën 2CV, Renault 4, some Peugeot 106s and Citroën Saxos, and the Tata Nano). Compact cars may have four bolts

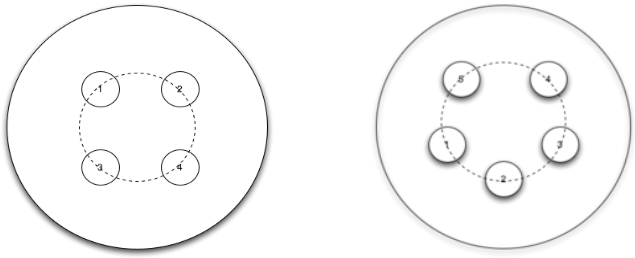

Fig.9 Bolt patterns

Four Hole and Five Hole Bolt Pattern

Bolt circle: The bolt circle is the notional circle determined by the positions of the bolts. The center of every bolt lies on the circumference of the bolt circle. The important measurement is the bolt circle diameter (BCD),also called the *pitch circle diameter* (PCD).

Determining the bolt circle:

For a 4- or 6-bolt wheel, this measurement is merely the distance between the center of two diametrically opposite bolts. In the 4-bolt picture above, this would be the distance between holes #1 and #4, for example.

Some basic geometry is needed to find the center of a 5-bolt pattern. In practice, the BCD can be found by multiplying the center distance between any two adjacent holes by 1.701.

BCD geometry of 5-bolt pattern

$$\sin(\text{half top angle}) = \frac{\text{center distance}}{2 \times \text{radius}}$$

Or

$$\text{radius} = \frac{\text{center distance}}{2 \times \sin(\text{half top angle})}$$

half the top angle of a 5-bolt wheel is:

$$\frac{360^\circ}{5} \times \frac{1}{2} = 36^\circ$$

using a unity center distance of 1, a bolt circle diameter

= 2 × radius, and sin(36) = 0.58778:

$$BCD = 2 \times \frac{1}{2 \times 0.58778} = 1.701$$

Generally, the BCD *b* can be calculated for any wheel from the number of bolts *n* and the center distance *d* between two adjacent bolts as:

$$b = \frac{d}{\sin\left(\frac{1}{n}180^\circ\right)}$$

A far easier way, using less math, is to take calipers and measure the hole size in the center of the wheel (note half of this dimension). Next measure the distance between the edge of the center hole and the center of one stud. Double this measurement and add it to the Noted sum. Job done! (That is determine the radius of the hole size, not the diameter) This method works with any number of studs.

Pressures and forces acting on wheel: The inflation pressure of bicycle tires ranges from below 2 bar (200 kPa; 29 psi) for tubeless mountain bike tires to 15 bar (1,500 kPa; 218 psi) for tubular track racing tires. The pressure rating of tires is usually stamped somewhere on the sidewall. It may be indicated as "Maximum Pressure", or "Inflate to ..." and is usually expressed as a range (for example, "6–8 bar or 600–800 kPa or 87–116 psi". Inflating to the lower number in the pressure range will tend to increase traction and make the ride more comfortable. Inflating to the higher number will tend to make the ride more efficient and will decrease the chances of getting a flat tire.

One published guideline for clincher inflation pressure is to pick the value for each wheel that produces a 15% reduction in the distance between the wheel rim and the ground when loaded (i.e. with the rider and cargo) compared to when unloaded. Pressures below this lead to increased rolling resistance and likelihood of pinch-flats. Pressures above this lead to less rolling resistance in the tire itself, but to larger energy losses in the frame and rider. Bicycle tires are essentially thin-walled pressure vessels and so the circumferential force in the casing is directly proportional to the internal pressure and to the tire diameter, and the force in the longitudinal direction is half of this.Inner tubes are not completely impermeable to air and slowly lose pressure over time. Butyl inner tubes hold pressure better than latex. Tires inflated from carbon dioxide canisters (often used for roadside repairs) or helium (occasionally used for elite track racing) lose pressure more quickly, because the first gas, despite being a large molecule, is slightly soluble in rubber, and the second is a very small atom which passes quickly through any porous material. At least one public bicycle sharing system, Bixi, is inflating tires with nitrogen, instead of simple air, which is already 78% nitrogen, in an attempt to keep the tires at the proper inflation pressure longer, though the effectiveness of this is debatable.

Effect of temperature:

Since the volume of gas and the gas itself inside a tire is not altered significantly by a change of temperature, the ideal gas law states that the pressure of the gas should be directly proportional to the absolute temperature. Thus, if a tire is inflated to 4 bar (400 kPa; 58 psi) at room temperature, 20 °C (68 °F), the pressure will increase to 4.4 bar (440 kPa; 64 psi) (+6%) at 40 °C (104 °F) and decrease to 3.6 bar (360 kPa; 52 psi) (-13%) at −20 °C (−4 °F).

Effect of atmospheric pressure:

The net air pressure on the tire is the difference between the internal inflation pressure and the external atmospheric pressure, 1 bar (100 kPa; 15 psi), and most tire pressure gauges report this difference. If a tire is inflated to 4 bar (400 kPa; 58 psi) at sea level, the absolute internal pressure would be 5.15 bar (515 kPa; 74.7 psi) (+24%), and this is the pressure that the tire would need to contain if it were moved to a location with no atmospheric pressure, such as the vacuum of free space. At the highest elevation of commercial air travel, 12,000 meters (39,000 ft), the atmospheric pressure is reduced to 0.2 bar (20 kPa; 2.9 psi), and that same tire would have to contain 4.95 bar (495 kPa; 71.8 psi) (+20%).

Rim width:

While not strictly a tire parameter, the width of the rim on which any given tire is mounted has an influence on the size and shape of the contact patch, and possibly the rolling resistance and handling characteristics. The European Tyre and Rim Technical Organization (ETRTO) publishes a guideline of recommended rim widths for different tire widths.

Forces and moments generated:

Bicycle tires generate forces and moments between the wheel rim and the pavement that can effect bicycle performance, stability, and handling.

Vertical force:

The vertical force generated by a bicycle tire is approximately equal to the product of inflation pressure and contact patch area. In reality, is it usually slightly more than this because of the small but finite rigidity of the sidewalls.Tyres, increases with inflation the vertical stiffness, or spring rate, of a bicycle tire, as with motorcycle and automobile pressure.

Rolling resistance:

Rolling resistance is a complex function of the materials and construction methods used and the inflation pressure, with higher pressure (up to a limit), thinner casing layers, wider tires (compared to narrower tires at the same pressure and of the same material and construction), larger-diameter wheels, and more-elastic tread material all tending to have less rolling resistance. Rolling resistance coefficients may vary from 0.002 to 0.010, and have been found to decrease with inflation pressure and increase with vertical load. A study at the University of Oldenburg found that Schwalbe Standard GW HS 159 tires have a Crr of 0.00455 for the ISO size 47-406 (20 in x 1.5 in) and, for the same model tire, a Crr of 0.00336 for the ISO size 37-622 (700c): a size to resistance ratio of about −1.8.

IV. Analysis using ANSYS

ANSYS – IN STRUCTURAL MECHANICS

Structural mechanics solutions from ANSYS provide the ability to simulate every structural aspect of a product, including linear static analyses that simply provides stresses or deformations, modal analysis that determines vibration characteristics, through to advanced transient nonlinear phenomena involving dynamic effects and complex behaviors.

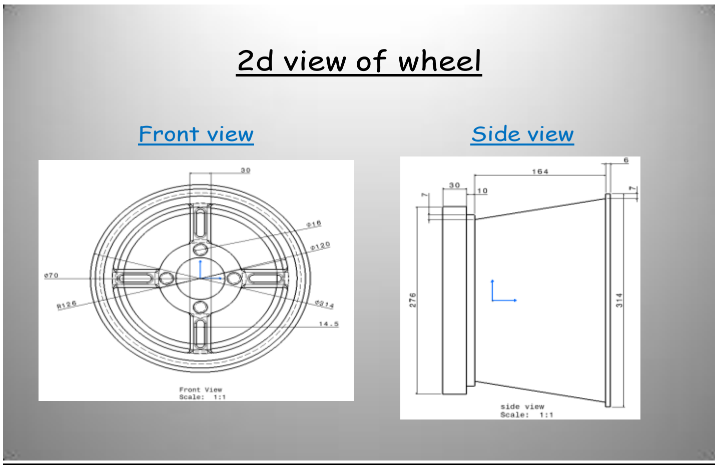

Fig.10 2D view of designed wheel

Material properties

Material	Aluminum 356	Steel	Magnesium Alloy AZ91D
Young's modulus	72400 MPa	210000 MPa	450000 MPa
Poisson's ratio	0.33	0.3	0.281
Density	2760 kg/m3	7850 kg/mm3	1810k g/m3
Tensile yield strength	229 MPa	250 MPa	230
Compressive yield strength	250 MPa	295 MPa	160
Tensile ultimate strength	279 MPa	400 MPa	220

Geometric model of alloy wheel

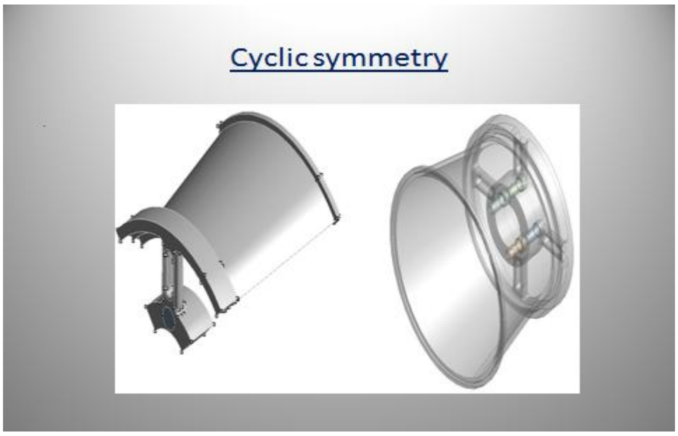

Fig.11 Geometric Model of the Alloy Wheel

Meshing

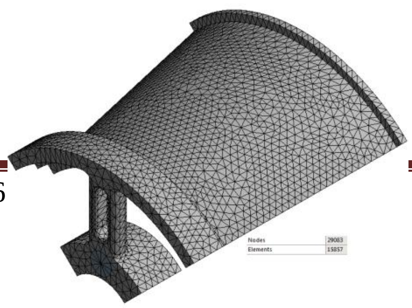

Fig.12 Shows the meshing of the Component and it has the 15857 of elements.

Boundary Conditions

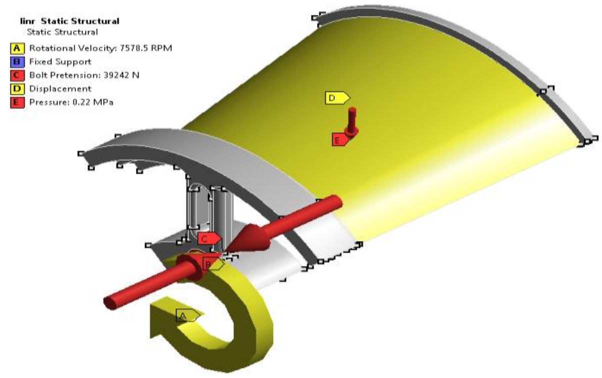

Fig.13 Boundary Conditions

The above Fig.5.7 shows the boundary conditions for a wheel which under goes rotational velocity, pressure due to tire, tube and bolt Pretension.

V. Result

Total Deformation

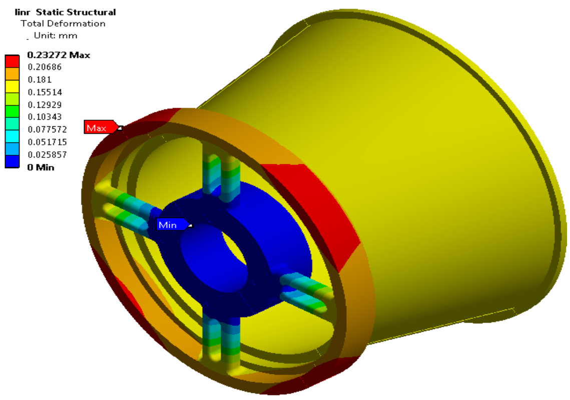

Fig.14 Total Deformation

Total deformation occurred is 0.23 mm.

Equivalent stress:

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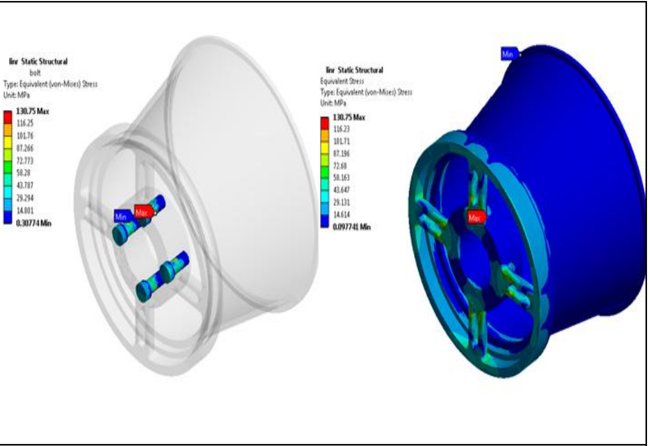

Fig.15 Equivalent stress of four armed rim

<u>Comparision between six armed and four armed wheel</u>

Specifications	Six armed wheel	Four armed wheel (Linear analysis)	Four armed wheel (Non-Linear analysis)
No. arms	6	4	4
No. of bolts used	6	4	4
Mass of the rim	7.0818kgs	5.1512kgs	5.1512kgs
Volume of the rim	2.6375e+6 cubic mm	1.9185e+6 cubic mm	1.9185e+6 cubic mm
Equivalent Stress	Max= 93.678mpa Min=0.05684mpa	Max=130.75mpa Min=0.09774mpa	Max=320.05mpa Min=0.70232mpa
Deformation	0.099246mm	0.23272mm	0.24772mm

Conclusion:

- Equivalent stressfor a 4 arms alloy wheel is 130 Mpa which is less than yield stress still it is in elastic deformation so it is safe
- Cyclicsymmetry is carried out for alloy wheel
- Buckling analysis is achieved
- Structural analysis carried out for the 6 arm alloy wheel and it is optimized to 4 arms,
- Number of bolts reduced 6 bolts to 4bolts
- Mass of 6 arm alloy wheel is 7.0818 Kg and mass of 4 arms alloy wheel is 5.1512Kg due to the optimization it reduces to 1.9306 kg and reduced percentage is 27.26%
- Stress and deformation will be more but as per material yielding value stress and deformations in safe.

Specifications	Six Arms	Four arms	% of reduction
Number of bolts	6	4	2 bolts
Mass of rim	7.0818 Kg	5.1512	27.26%
Equivalent stress	93 Mpa	130 Mpa	
Total deformation	0.99246 mm	0.2324	

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