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Static Analysis on Custom Polyurethane Spokes of Airless Tire

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Abstract- The airless tire is a single unit replacing the pneumatic tire, wheel and valve assembly. It replaces all the components of a typical radial tire and is comprised of a rigid hub, connected to a shear band by means of flexible, deformable polyurethane spokes and a tread band, all functioning as a single unit. The Tweel, a kind of airless tire, though finds its generic application in military and earth moving applications due to its flat proof design can also render the pneumatic tire obsolete in domestic cars.

Our project involves fabrication of an airless tire prototype for domestic cars; this will be followed by a stress analysis study of the prototype. The study has been done on the SolidWorks design package wherein – stress and deflection studies have been performed.

Index Terms- Airless tire, Michelin^R, Pneumatic tire, SolidWorks, Tweel.

I. Introduction

Michelin first announced the Tweel in 2005. The name is a combination of the words tire and wheel because the Tweel doesn’t use a traditional wheel hub assembly. A solid inner hub mounts to the axle that’s surrounded by polyurethane spokes arrayed in a pattern of wedges. A shear band is stretched across the spokes, forming the outer edge of the tire (the part that comes in contact with the road). The tension of the shear band on the spokes and the strength of the spokes themselves replace the air pressure of a traditional tire. The tread is then attached to the shear band. When the Tweel is put to the road, the spokes absorb road impacts the same way air pressure does in pneumatic tires. The tread and shear bands deform temporarily as the spokes bend, then quickly spring back into shape.

Airless tires can be made with different spoke tensions, allowing for different handling characteristics. The lateral stiffness of the tire is also adjustable.

1) Drawbacks of Pneumatic tire

One of the basic shortcomings of a tire filled with air is that the inflation pressure is distributed equally around the tire, both up and down (vertically) as well as side-to side (laterally). That property keeps the tire round, but it also means that raising the pressure to improve cornering - increasing lateral stiffness - also adds up-down stiffness, making the ride harsh.

II. HISTORY

For more than 100 years, vehicles have been rolling along on cushions of air encased in rubber. The pneumatic tire has served drivers and passengers well on road and off, but a new design by Michelin could change all that – the Tweel Airless tire. This report discusses what such Airless Tires are, why one would use it in place of traditional tires, some of the problems that may occur with an airless tire and where one might see such Airless Tire in the future. When the tire is put to the road, the spokes absorb road impacts the same way air pressure does in pneumatic tires. The tread and shear bands deform temporarily as the spokes bend, then quickly spring back into shape. Airless tires can be made with different spoke tensions, allowing for different handling characteristics. More pliant spokes result in a more comfortable ride with improved handling. The lateral stiffness of the tire is also adjustable. However, you can’t adjust a such a tire once it has been manufactured. You’ll have to select a different one. For testing, Michelin equipped an Audi A4 with Tweels made with five times as much lateral stiffness as a pneumatic tire, resulting in “very responsive handling”. Non-pneumatic tires (NPT), or Airless tire**s**, are tires that are not supported by air pressure. They are used on some small vehicles such as riding lawn mowers and motorized golf carts. They are also used on heavy equipment such as backhoes, which are required to operate on sites such as building demolition, where tire punctures are likely. Tires composed of closed-cell polyurethane foam are also made for bicycles and wheelchairs. The main advantage of airless tires is that they cannot go flat, but they are far less common than air filled tires.

Airless tires generally have higher rolling resistance and provide much less suspension than similarly shaped and sized pneumatic tires. Other problems for airless tires include dissipating the heat buildup that occurs when they are driven. Airless tires are often filled with compressed polymers (plastic), rather than air.

Michelin is currently developing an integrated tire and wheel combination, the "Tweel" (derived from "tire" and "wheel," which, as the name "Tweel" suggests, are combined into one new, fused part), that operates entirely without air. Michelin claims its "Tweel" has load carrying, shock absorbing, and handling characteristics that compare favorably to conventional pneumatic tires.

Automotive engineering group of mechanical engineering department at Clemson University is developing a low energy loss airless tire with Michelin through the NIST ATP project. Resilient Technologies and the University of Wisconsin–Madison's Polymer Engineering Center are creating a "non-

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pneumatic tire", which is basically a round polymeric honeycomb wrapped with a thick, black tread. The initial version of the tire is for the SUVs and is expected to be available in 2012.Resilient Technologies airless tires have been tested and are used by the U.S. Army.

III. CALCULATIONS

The following calculations undertake the Shaft design, key design and rim design. Assumptions made during the calculations are underpinned.

1) Shaft Design

The shaft is a rod of circular cross section which is used in transmission of power over a long distance and also for load supporting. Axle shafts are used for transmitting rotating motion of cam shaft to wheels. The following values are assumed to design the axle shaft:

Weight of car= 1.5ton

Power =100HP.

Tire diameter=500mm

RPM of tire, $N_{1=}$6000 RPM.

Material of the shaft is assumed to be Cast Iron Gr3.Coressponding to the material the following values are obtained from PSG DATA BOOK.

Tensile Stress = 520N/mm^2.

Bending Stress = 270N/mm^2.

Shear Stress = 100N/mm^2.

Bending moment, M=5886Nm

Twisting moment, T=3000Nm

Te= $((1.5x5880)^2+ (1.2X3000)^2)^{1/2}$=9526.4 Nm

Te $\leq (\pi/16)$ x 100x d^3.

9520X$10^3 \leq (\pi/16)$ x 100 x d^3

Diameter of shaft= 80mm.

2) Key Dimensions

Keys are used as fasteners so that both shaft and the mounted elements rotate together. The following calculations are performed keeping in mind the" Pin key" type

d'=0.2xd.

Diameter of key=16mm.

3) Design of Rim

Rim is the skeleton of the tire and is the hardest part of the wheel. It provides rigidity to the wheel and it is also responsible for transmission of power. Material of the rim is considered to be Alloy Steel SS.

Density of material = 7700 kg/m^3.

Tensile Strength = 723825617 N/mm^2.

Poisson's ratio = 0.28

Velocity of rim, V_1=120km/hr.

Stress S_t=density x v^2

S_t=7700x120x5/18

S_t=256666.6 N/m^2.

The calculated stress value is less than tensile value of rim, therefore assumed velocity is in the safe limit.

$V_1=\pi$ x D x N/60

N=3350.526 RPM

The rim speed is well under the standard speed of the shaft, so it is under the safety limit of the wheel.

3.1) Rim Thickness

t = D/200 + 6

t = 0.36/200 + 6

t= 8mm

3.2) Dimensions of arms in the Rim

Load on each wheel =0.375 ton = 375 kg.

Compressive stress of material = 180956404.3 N/mm^2.

Load = n x cross section area x compressive stress of material.

The number of arms in each rim is assumed to be 4 i.e.. n=4

Area of each arm = 0.01 x 0.01 = 1 x 10^{-4} m^2.

Compressive load = 3678.75 /0.01^2 x 4 = 9197125N/mm^2.

The compressive stress of design by calculation is much lesser than the actual compressive stress of the material and well under the safety limit.

3.3) Dimensions of hub

The d_i is the inner diameter of the hub of the tweel.The d_o is the outer diameter of the hub and the d_s is the diameter of the shaft which is equal to 80mm.The d_i is equal to $d_{s.}$

The d_o=1.5d_s+25,

The d_o=2d_s (PSG DATA BOOK) for safe limits,

The d_o is 160mm

The Length of the hub is calculated to be 15 mm.

4) Final Calculated Values

Diameter of shaft = 80mm

Diameter of key = 16mm

Diameter of rim = 360mm

Number of arms = 4

Dimensions of arms: x=10mm
y =10mm

Diameter of the hub: Inner diameter = 80mm
Outer diameter = 160mm

Length of the hub = 15mm

IV. ANALYSIS

According to the International Standard a pneumatic tire is required to be inflated up to 25 psi in order to have a proper air cushion for drive comfort and fuel efficiency. This air pressure is subject extrinsic properties like temperature. As per a study performed on Yamuna Expressway, the tire pressure after an hour of continuous journey the air pressure inside the tube of pneumatic tire reaches up to 56 psi.

To simulate such dynamic environment the spokes are under the subjugation of force, torque and pressure due to car's weight and acceleration. The spokes were under following conditions:

Table 1.The values of these extensive parameters are decided to depict the harshest condition a tire can withstand in normal on road performance.

Pressure	1.033e+005 N/m^2
Force	10000 N
Torque	11230 N-m

The conditions that are simulated are of zero initial velocity and positive acceleration. This is a scenario where the car has to

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overcome static friction and the wheels posses' higher stress.
In such cases the design of spokes is significant in deciding the load bearing capacity and the materials elasticity. Therefore both design and material of spokes, is pivotal in the success of airless

Fig1. Isometric view of the wheel design .The design procedure is performed on the SolidWorks design package basedon the calculated parameters.

A. Material properties

The material property of the polyurethane polymer used in spokes of the tweel are listed below.These valuese are utilized in the static stress analysis on the wheel.

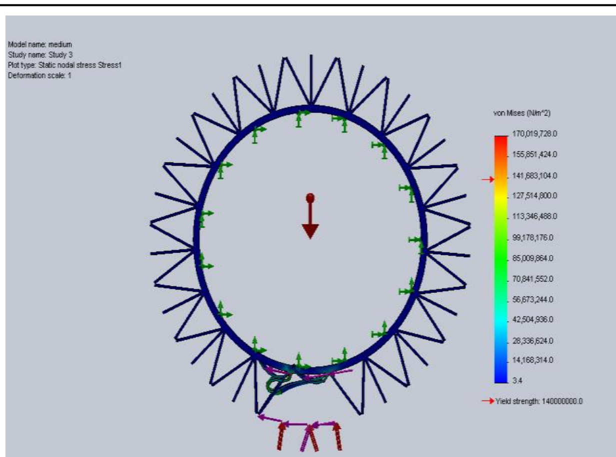

Fig.2. Stress analysis of wheel spokes subjected to high torque, pressure and normal forces on the wheel face.

Table 2.Material Properties

Mass density	1200	kg/m^3
Tensile strength	3e+007	N/m^2
Compressive strength	1.38e+009	N/m^2
Yield strength	1.4e+008	N/m^2
Thermal expansion coefficient	1e-006	/Kelvin
Thermal conductivity	0.209	W/(m.K)
Specific heat	1386	J/(kg.K)
Material damping ratio	0.4	NA
Elastic Modulus	6e+008	N/m^2
Poisson's Ratio	0.23	NA
Shear Modulus	2.5e+007	N/m^2

Table 2.Material Properties

V.RESULT

The maximum deflection in the spokes that are subjected to the aforementioned stress, torque and pressure values, are within the maximum permissible limits dictated by the material properties. It is found out from the analysis that the design is structurally rigid and stable to withstand all the simulated conditions and enough ductile to retreat to its original dimensions.

Table 3.Results of the simulation

Name	Min	Max
Stress	3.36838 N/m^2	1.7002e+008 N/m^2
Displacement	0 mm	130.165 mm
Strain	1.14799e-008	0.187904

VI.CONCLUSION

The spoke's design has performed satisfactorily under pre de- -fined static conditions. The stress and deformation of material in these conditions is under permissible limits of material properties.

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