Design and Analysis of Non-Pneumatic Tyre (NPT) with Twell Spokes Structures

Umesh G C[1], Amith Kumar S N[2]
[1, 2] Department of Mechanical Engineering
[1, 2] Dr.AIT, Bengaluru, Karnataka, India

Abstract- *A conventional tyre is made up of air enclosed rubber packed by means of compressed air. Conventional tyres over period have been dominating the world marketplace because it exhibits ride excellence and robustness. But it has disadvantaged such as burst out while driving, compound manufacturing method, the necessity to keep interior pressure. An innovative technology is under advancement to exploit only one of its kind blends of materials and geometry that does not need compressed air to hold up the load. Hence non-pneumatic tyres were introduced. The airless tyre is a single unit replacing the pneumatic tyre, wheel and valve assembly. It replaces all the components of a typical radial tyre 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 tyre, though finds its generic application in military and earth moving applications due to its flat proof design can also render the pneumatic tyre obsolete in domestic cars. We investigated twell spokes designed for non-pneumatic tyre by applying uni-axial load. The spokes experience tension as well as compression while they are rolling. So spokes required to have stiffness and rigidity. Non-pneumatic tyre is designed in ANSYS Workbench, twell tyre. ANSYS finite element analysis is worn to find deformation and stress in twell tyres.*

Keywords- Tyre, Non-pneumatic tyre, honeycomb, Ansys, Analysis

I. INTRODUCTION

For centuries, vehicles have been moving along on pads of air enclosed in rubber. Now and then, we get so used to a specific item that no genuine changes are ever truly made for quite a long time, decades even. So starts with an article talking about the advancement of airless tires somewhat that has turned out to be more common in the previous couple of years. A small number of tire organizations have begun exploring different avenues regarding plans for non-pneumatic tires including Michelin and Bridgestone, however neither one of the designs has made it to large scale manufacturing.

Making another non-pneumatic configuration for tires has more positive consequences than one might expect. First off, there are enormous safety advantages. Having an airless tire implies there is no risk of a burst, which in turns reduces number of accidents that occurs on highways. This positive implication benefits for situation such as Hamvees(high mobility multipurpose wheeled vehicle) in the military. The use of non-pneumatic tires in military vehicles has an immense impact on safety. Tires are the weak zone where enemy personal will target with explosives. If these military vehicle tires are replaced with airless tires, this would never again be a worry situation.

As a result of the advantages, I trust that it is critical that exploration and creation of airless tires is preceded and expanded. This kind of advancement functions admirably in conjunction with some engineering codes of morals and in this manner has to be grasped by specialists all around. Autos are things that individuals utilize each day, so any enhancements over existing outlines would influence the lives of the bulk of individuals. Knowledge regarding such a subject, consequently, I trust holds compelling quality particularly for us emerging engineers. In doing study into these sorts of subjects that hold remarkable significance, we can see that what we will do can have any kind of effect.

A. Non-pnumatic tyre Nomenclature:

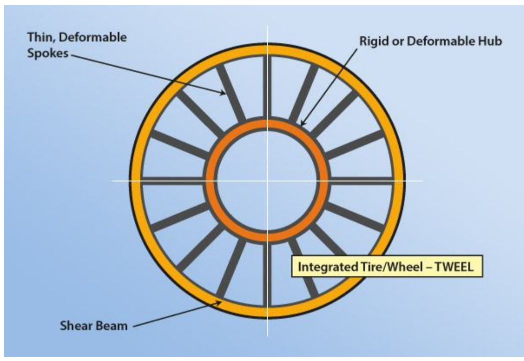

Fig. 1: Schematic representation of non-pneumatic tyre

The Airless tyre (Tweel) doesn't utilize a conventional wheel hub assembly. A strong alloy hub mounted to the transmission and is bounded by polyurethane spokes arranged in different shape of wedges. A shear band is extended over the spokes, shaping the external edge of the tire. On it thread is placed, the part that interacts with the surface of the ground. The air filled rubber enclosed tires are replaced by the deformable high spiffiness spokes, which get the strain of the shear band. Positioned on the shear band is the tread, the part that reaches the surface of the ground. At the point when the Tweel is running on the surface, the spokes withstand surface loads the same way as conventional tires. The shear band and flexible thread deform provisionally as the spokes twist, and then rapidly regains its shape. Dissimilar spoke tensions can be utilized, as essential by the usage characteristics and lateral stiffness can also differ. Conversely, once created the Tweel's spoke tension and parallel firmness can't be balanced.

II. LITERATURE SURVEY

Scott R pajtas et al, [1] conducted study on non-pneumatic tyres. He replaced conventional tyres with ring of elastomeric material referred to as "ride enhancing insert", which is pre-positioned on the outer surface of the wheel. Since elastomers is used this will survive normal use on various vehicles, as a replacement for a conventional spare tyre in automobile. He stated that RI is tolerant of stress and heat loads generated by operation of non-pneumatic tyres, so he concluded that to increase the degree of ride enhancement can be custom-made by choosing the size and shape of RI, along with the physical properties of elastomers from which it is formed. US5265659A.

Mohammad Fazelpour et al, [2] stayed considered about the progress of meso-structures in the improvement of the shear band of non-pneumatic tyre and he concluded as follows below. To increase fuel efficiency in NASA manned exploration system. They replaced elastomeric material with shear of shear band by means of materials which can bear insensitive temperatures and shear loads or else to substitute the materials with linear elastic low-hysteretic loss materials. Topologies were created such as honeycombs; innovative shapes like s-type meso-structures and the structural analysis were carried out of shear band of non-pneumatic tyre among meso-structure was investigated throughout shear flexure, shear strain, and contact pressure. At the end of research they set up procedure on custom-designing meso-structures for demanding applications like non-pneumatic tyre and inert morphing airfoils which determination is addressed in prospect study.

Jaehyung ju et al, [3] conducted study on non-pneumatic tyre which is accepting expanded consideration because of potential preferences above conventional tyres, counting attributes of moving confrontation. Their investigation concentrated going on the outline of a NPT in view of properties of perpendicular firmness with moving vitality misfortune. Utilizing a finite component display, a parametric learning led to think about the impact under vertical firmness along with RR reaction bearing in mind two configuration variables; (a) width of the spokes (b) the shear band width of NPT. Utilizing these two geometric variables, an outline of analyses is performed to ponder the impact on individual RR. Consequences as of the DOE are utilized to make reaction exterior models for individual the goal capacity (negligible RR) with a limitation on perpendicular deflection. The expository RSM capacity is enhanced intended for minimizing the moving misfortune subjected to the given limitation. Furthermore outline affectability learning is conducted to assess the authority of the outline variables on the yield reaction. Outcome shows with the intention of mutually variables has significant impact under RR, by means of the shear band width have the more noteworthy impact.

III. METODOLOGY

Problem definition:

Non-pneumatic tyres usually have higher rolling opposition and offer much less suspension then on the contrary shaped and sized pneumatic tyre. Additional troubles for airless tyre contain dissipating the heat built-up that arises when they are driven. Non-pneumatic tyres are often packed with compacted polymers, relatively to air.

Bearing in mind the non-pneumatic tyre structure, the spokes experience compression and tension under cyclic loading while the tire rolls. Therefore, it is essential to reduce the localized stress of spokes that is, the spokes must be fatigue resistance.

The non-pneumatic tyre based on Twell spoke pair is designed to replace convectional alloy spokes with elastomer. The spokes of non-pneumatic tyres are essential to include individual firmness and flexibility below repeated compression–tension loading. In common, stiffness and resilience are at variance necessities but materials have an elevated modulus, it shows a little elastic strain limit. Confront be near design materials to have individual elevated firmness and elevated flexibility.

IV. CAD MODEL

Design of spokes structure:

The twell spoke is designed using ANSYS workbench. The whole structure is divided in to cell. Each cell consists of pair of inclined spokes and the angle between cells is$18°$. The cell resembles the trapezoid structure. The dimensions of single cell are shown in figure 2. Single spoke has a wall thickness of 5mm and the base of trapezoid is 36mm and upper part of trapezoid is 26mm. The base of trapezoid is formed above the circumference of the hub while the top of trapezoid is formed below the inner circumference of the wheel. The height of the trapezoid is 200 mm.

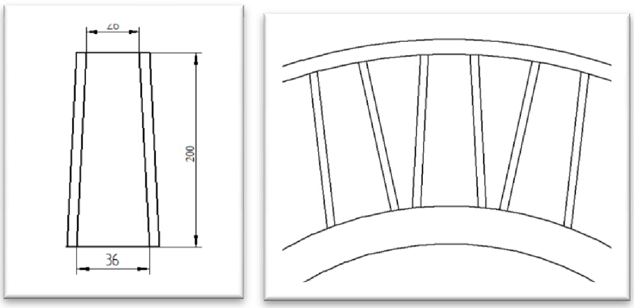

Figure 2: Geometric dimensions of twell structures

Twell spokes are considered to substitute the usual spokes in the vehicle wheel. Twell spokes comprise of incline structure, thickness, and as well diverge from radial line. The spokes are paired and positioned at equal distance along the boundary of the twell. The spokes in the twell model have a unique inclination, prearranged in an interlacing manner. This type of structure enables them to flex well without twisting still providing sufficient strength to withstand cyclic loads. These designed have light weight structures. The main intention of the spokes is to contain low stiffness; as a result it is essential to have both stiffness and resilience under cyclic loading. The spokes are made up of polyurethane to replace air enclosed pneumatic tyres.

CAD Model of Twell

3D model of twell structured non-pneumatic tyre

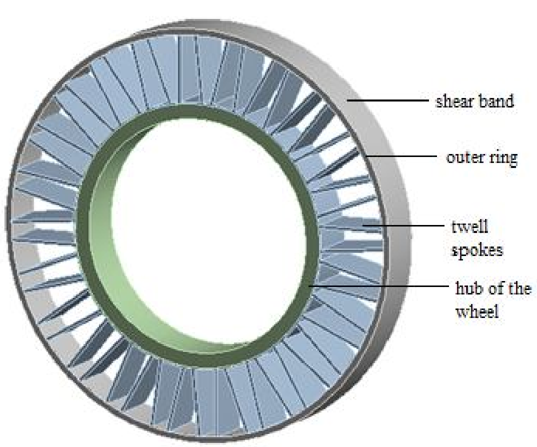

Figure 3: 3D model twell non-pneumatic tyre made by using ANSYS workbench

The figure 4 shows the collection of pair of inclined spokes structure tire called twell non-pneumatic tyre. The 3D twell airless tire model was produced using ANSYS workbench. The modeling of tire involves different steps such as sketching, protrusion; revolving, mirror is created as per standard tyre dimension.

Geometrical aspects:
The wheel size is 25”×6.5”×15”
The hub or rim diameter is = 380.1 mm.
Hub thickness is = 25 mm.
The outer ring diameter is = 605 mm.
The outer diameter of the wheel is =625 mm.
The thickness of shear band is = 15 mm.
The width of the wheel is = 165.1 mm.

V. FINITE ELEMENT MODELLING

A. Finite Element method:

The FEM (finite element method) is a numerical technique used to resolve problems which is described by differential equations (partial differential equations) or can be resolved as functional minimization. In finite elements approximating functions are determined with the help of nodal values of a continuum which is sought. The continuum or physical problem is converted into a discretized small finite element problem with unknown nodal values. FEM is a computer program utilize to analyze a material and to find how stresses will affect the design or material for the applied load.

B. Meshed Twell tyre model:

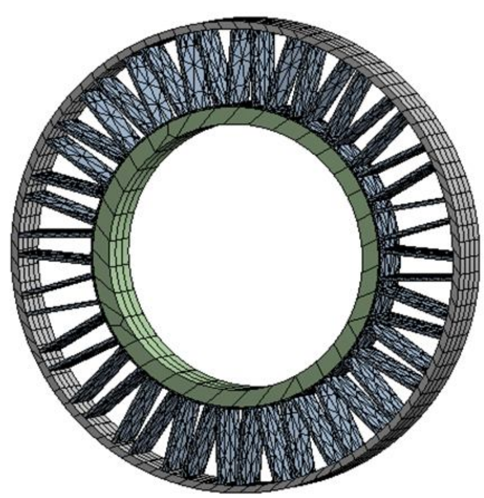

Fig 5: Meshed model of twell tyre

The fig 5 shows the meshed model of twell spokes structured tyre. Meshing is carried out using ansys software. Hear we used tetrahedral element for meshing. These tetrahedral elements are 3D elements which are having 3 degree of freedom at each node. These tetrahedral (Solid187) elements are the translational DOF in all 3 directions .i.e. x, y, and z. Tetrahedral element captures complete behavior of components by creating appropriate mathematical model during analysis. These elements capture minute details. The total number of nodes in the meshed model is 14613 and total number of elements is 7470.

C. Material properties of twell tyre:

The materials used in this analysis for twell tyres are aluminium alloy, polyurethane, steel, syntactic rubber. The main reason for selecting these materials is because they pose wide range of mechanical properties like high stiffness and resilience, high flexibility, hyperelastic, high temperature resistance etc. Standard materials have been selected and the properties are shown in the table 1.

Table 1: Material properties of the elemental parts of non-pneumatic tyre

Part	Hub	Spokes	Outer ring	Shear band
Material	UNS A97075	Polyurethane	AISI 4140	Syntactic rubber
Yield strength, (MPa)	503	145	480	18.2
Elastic modulus, E (MPa)	75000	35	210000	14
Poisson's ratio, (υ)	0.33	0.48	0.3	0.48
Density, (ρ) Kg/m^3	2180	1210	7810	1050
Shear modulus, G (MPa)	32000	11.18	80000	3.5

D. Boundary conditions:

The inner surface of the wheel is completely constrained in all direction. Rotational velocity of 5000 rpm is applied in z-direction and x-component is left free for deformation since not much deformation occurs in the other two directions. It is shown in fig 6. A load of 750 N is applied in the y-direction as shown in fig 6. For this applied load equivalent stress and deformation are evaluated.

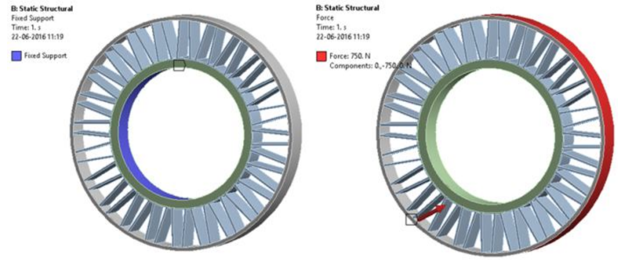

Fig 6: Boundary conditions for twell tyre

Solver and post processor:

The linear static analysis and model analysis is carried out on non-pneumatic tyre for the above load cases. The commercial FE solver ANSYS V13.0 version is used for numerical solutions. The results are post processed using ANSYS V13.0.

VI. RESULTS AND DISCUSSION

The linear static analysis is performed on non-pneumatic tyre for various load condition to assess the structural strength for Design verification procedure load cases. The materials are considered in this analysis.

A. Liner static analysis:

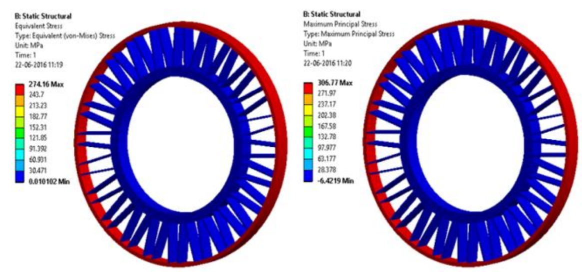

Fig 7: Von-mises and Maximum principal stress

The figure 7 shows the equivalent and maximum principal stress for twell airless tire. Maximum equivalent and principal stress valves are 274.16 MPa and 306.77 MPa. In the above figure a small amount of red colour indicates the maximum equivalent and principal stress and blue colour indicates the minimum equivalent and principal stress.

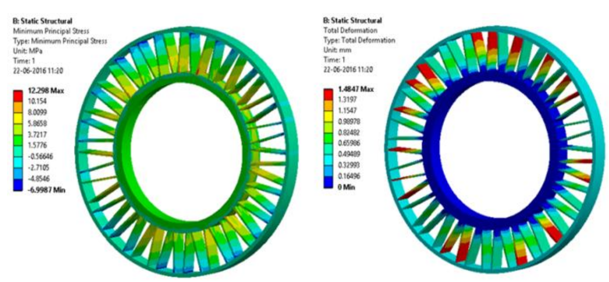

Fig 8: Minimum principal stress and Total deformation

The figure 8 shows the minimum principal stress and total deformation. A red colour indicates the maximum value of stress and maximum deformation. The minimum principal stress value is 12.298 Mpa and the maximum deformation value is 1.1847 mm and it is shown in red colour. Minimum value is shown in blue colour shade.

B. Model analysis:

The Modal Analysis is performed to evaluate the natural frequency of the non-pneumatic tyre and its mode shape. The natural frequencies of the non-pneumatic tyre should not fall between the operating frequency ranges to avoid the structure failure due to resonance. In this project we conducted model analysis to determine different natural frequency and mode shapes. This occurs for the applied static load of 750 N.

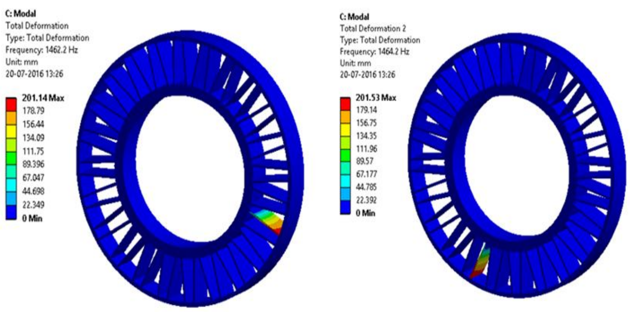

Fig 9: first and second mode of deformation

In the fig 9 shows the first and second mode of vibration for the applied load. The first mode occurs at first natural frequency ω_1 = 1462.2 Hz and total deformation value for this first mode is 201.14 mm. The second mode occurs at second natural frequency ω_2 = 1464.2 Hz and total deformation value for the second mode is 201.53 mm. The red colour indicates the total deformation.

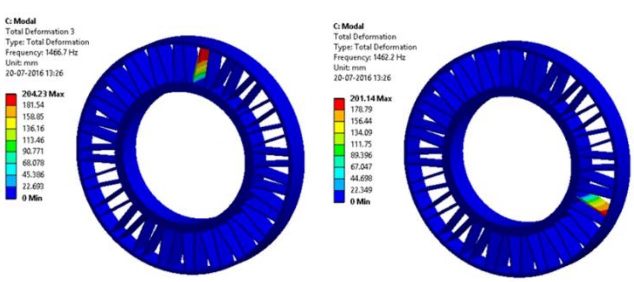

Fig 10: Third and Fourth mode of deformation

In the fig 4.16 shows third and forth mode of vibration for the applied load. The third mode occurs at third natural frequency ω_3 = 1466.7 Hz and total deformation value for this third mode is 204.23 mm. The fourth mode occurs at fourth natural frequency ω_4 = 1468.0 Hz and total deformation value for the fourth mode is 205.14 mm. The red colour indicates the total deformation.

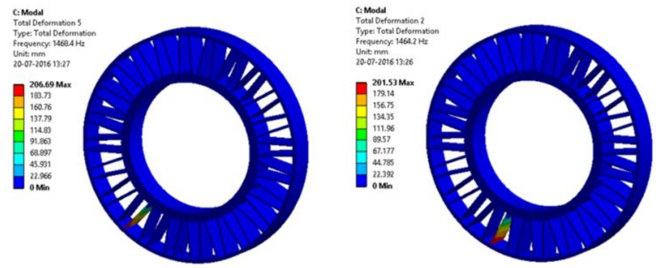

Fig 5.18: Fifth and Sixth mode of deformation

In the fig 4.17 shows the fifth and sixth mode of vibration for the applied load. The fifth mode occurs at fifth natural frequency ω_5 = 1468.4 Hz and total deformation value for this fifth mode is 206.69 mm. The sixth mode occurs at sixth natural frequency ω_6 = 1469.0 Hz and total deformation value for the sixth mode is 207.53 mm. The red colour indicates the total deformation.

VII. CONCLUSION

- The static analysis of twell tyre had been carried out. The equivalent stress value obtained in static analysis for honeycomb tyre is 274.16 MPa which is above permissible limits of material properties. So the structure is not safe.
- The deformation value of twell tyre spoke is 1.1847 mm.
- Resluts shows that the designed spoke structure is not safe for the applied loading condition.
- The stress in the spoke are excceding the permissible value.

REFERENCES

[1] Mohammad Fazelpoue "A comparison of design approaches to meso-structure development". ASME journal paper DETC 2013-12295, 2013, doi: 10.115/ DETC 2013-12295.

[2] A.M. Aboul-Yazid., "Effect of spokes structure on characteristics performance of non-Pneumatic tyres," ISSN: 2180-1606 Volume 11, pp. 2212-2223, January-June 2015.

[3] Bert Bras., "Life-cycle environmental impact of Michelin tweel tyre for passenger vehicles" SAE International Journal 2011-01-0093, 2011, doi: 10.4271/2011-01-0093.

[4] Pajtas, S., "Polyurethane non-pneumatic tyres technology-development and testing history," SAE Technical Paper 900763, 1990, doi: 10.4271/900763.

[5] Jaehyung, Ju., “Optimization of Geometry and Material properties of a non-pneumatic tyre for reducing rolling resistance” Int. J. Vehicle Design, Vol. 66, No. 2, 2014.

[6] Kim, K. and Kim, D., "Contact pressure of non-pneumatic tyres with hexagonal lattice spokes," SAE Technical Paper 2011-01-0099, 2011, doi: 10.4271/2011-01-0099.

[7] Joseph, P., "Design of cellular shear bands of a non-Pneumatic tyre -investigation of contact Pressure" *SAE Int. J. Passeng. Cars – Mech. Syst.* 3(1):598-606, 2010, doi: 10.4271/2010-01-0768.

[8] You-Qun Zhao, “Non-pneumatic mechanical elastic wheel natural dynamic characteristics and influencing factors” Journal of Central South University May 2015, Volume 22, *Issue 5,* pp 1707 -1715

AUTHORS

First Author: Umesh.G.C, M.Tech student, Dr.AIT, Bangaluru, Karnataka, India,E-mail: umeshgcs@gmail.com

Second Author: Amith Kumar.S.N, Assistant Professor, Department of Mechanical Engineering, Dr.AIT, Bangaluru, Karnataka, India, E-mail: amithkumar59@gmail.com