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Design and analysis of a bicycle wheel spokes and their effects of the number of spokes on their stiffness

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Abstract: The purpose of this investigation is to evaluate the effects that the number of spokes have on the radial stiffness of a bicycle wheel. For this investigation, three bicycle wheels with 28, 32, and 36 radial spokes were modeled as two dimensional nonlinear static stress models using a finite element analysis (FEA) software. These wheels were subjected to a radial load only. The stresses, forces and displacements of each model were compared to determine the relationship between the number of spokes and the radial stiffness of the wheel. Based on the FEA results, the radial stiffness increased with increasing number of spokes, as expected. The stresses and forces in the spokes and the displacements of the bottom spoke decreased as more spokes were added to the wheel. Additionally, the pre tensioned lower spokes had reduced in tension while the rest of the spokes slightly increased in tension.

Keywords: Motorcycle wheel, spokes, modified design, lightweight alloy-wheel, stress analysis.

1. Introduction

The wheel is a load carrying device which has facilitated the transportation of goods and people. The circular form of the wheel is used in many machinery applications today such as gears and pulleys. The bicycle is a vehicle that utilizes wheels and is a good example of how wheels have evolved over centuries to more sophisticated designs. A bicycle wheel consists of wire spokes radiating outward from the hub, located at the center of the wheel, to the rim where the spokes are fastened to by threaded spoke nipples.

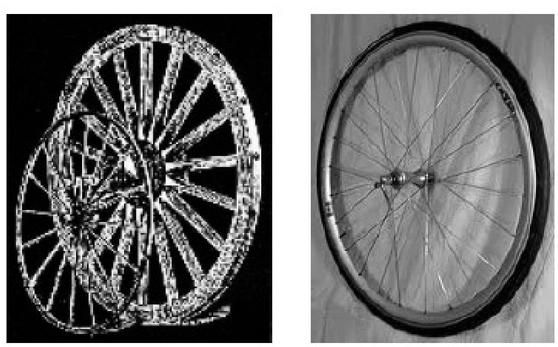

Figure 1: Antiquated wheels and a modern bicycle wheel.

Prior to the invention of the wire-spoked wheel, carriages and wagons had thick wooden-spoked wheels that were able to resist compressive loads. Around the middle of the nineteenth century (. Burgoyne, C.J,

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1993), wire-spoked wheels replaced wooden wheels due to their lightweight quality, durability and strength (see Figure 1). However, unlike their wooden counterparts, wire spokes are not compressible structures and therefore, would buckle under compression. To overcome this obstacle, the wire spokes are pre stressed in tension so that a compressive load would result in a reduction of pretension (see Figure 2).

Figure 2: Tension of a bicycle wheel spoke.

2. Methodology & approach

Three bicycle wheels (34, 38, and 42 radial-spoked wheels) were modeled as two dimensional structures using the FEA software Abaqus/CAE. The wire spokes, hub and rim were the only structural parts considered for this investigation. The other parts of the wheel, such as the axle, bearings and tire, do not play a role in affecting the wheel's stiffness (Lang, L.H, 2004). In the finite element models, the spokes and rim were created as one part using deformable wires in three dimensional space. Additionally, the hub was not modeled, to further simplify the analysis. Instead the spokes were pinned in the x, y, and z directions where the hub and spoke would meet (Wikipedia). The materials, mechanical properties, and geometric dimensions of the spoke and rim are summarized in Tables 3 and 4. The spoke material is 304 Stainless Steel. The type of spoke used for this analysis is a 2 mm straight gage spoke (see Figure 3). The spoke cross section is modeled as a circle and is assumed to be constant through the length of spoke. The cross section of the rim used was a hollow box with dimensions taken from Reference (6) (see Figure 4). The rim material is 6061-T6 Aluminum Alloy. These rim and spoke materials are commonly used to manufacture bicycle wheels.

Table1: Spoke and Rim Material and Mechanical Properties.

Bicycle Wheel Parts	Material	Mechanical Properties	
		Young's Modulus, E (ksi)	Poisson's Ratio, ν
Spokes	304 Stainless Steel	10,000 [7]	0.29 [7]
Rim	6061-T6 Aluminum Alloy	28,000 [7]	0.33 [7]

Table 2: Spoke and Rim Geometrics

Bicycle Wheel Parts	Geometry		
	Profile	Diameter (in)	Cross-Sectional Area (in^2)
Spokes	Circle	0.07874 (2 mm) [4]	0.004869
Rim	Box	22 (wheel diameter) [4]; See Figure 4 for other dimensions	0.1271
Hub	N/A	2	N/A

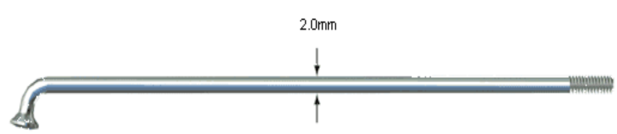

Figure 3: Straight gage spoke**.**

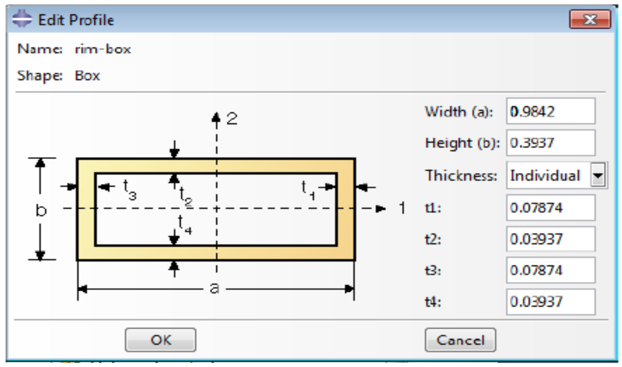

Figure 4: Rim Cross Section defined in Abaqus/CAE

The elements used to model the rim and spokes are linear 2-noded cubic beam elements (B33) and linear 2-noded three dimensional truss elements (T3D2), respectively. The truss elements can only support axial loads and therefore, are appropriate for modeling the spokes [8]. For all models, there are 10 truss elements along the length of the spokes and four beam elements along the rim in between each spoke. A mesh refinement study was performed to confirm that it was unnecessary because it did not affect the results. The type of analysis used in Abaqus/CAE was a nonlinear static stress analysis. The analysis is divided into two steps. The first step is to pretension the spokes. The second step is to apply the radial load. The loads applied to the bicycle wheel models are pretension and radial loads as shown in Figure 5. Bolt preload was added to each spoke to model the pretension. The value of the bolt preload varied for each model since it depended on the number of spokes (see Table 3). The total pretension was the same for each wheel. It was arbitrarily taken as the average of the recommended values in Reference (9) and multiplied by 28 spokes (approximately 6500 lbf). As for the radial load, the weight of an average human male (196 lbf [10]) was applied on the bottom rim as an upward force from the ground. Since only one wheel is modeled, the radial force is half of the weight (98 lbf).

Table 3: Pretension for each bicycle Wheel model.

Model	Total Pretension (lbf)	Pretension Per Spoke (lbf)
28 spokes	6500	232
32 spokes	6500	203
36 spokes	6500	181

The boundary conditions of the models are as follows: (1) the spokes at the hub end are pinned in the three orthogonal directions (UX=UY=UZ=0); and (2) the wheels are constrained in the XY plane to avoid out of plane bending (UZ=0). An example is shown in Figure 5.

3. Results and discussion

The results (stresses, forces and displacements) for each wheel were compared to observe the effect of increasing spoke number on the radial stiffness of a bicycle wheel. In Figure 6, the stresses on the spokes decreased as more spokes are added to the wheel. In the 28-spoked wheel, the stresses on the spokes range from 33,590 psi to 48,760 psi. In the 32-spoked wheel models, the stresses on the spokes range from 31,080 psi to 42,720 psi. Both of these models have three bottom spokes supporting the compressive load. In the

36-spoked wheel model, the rim distributed the load to five bottom spokes. The range of stresses for the 36-spoked wheel is 27,000 psi to 37,950 psi. Similarly, the compressive stresses in the rim decreased with increasing number of spokes (see Figure 7).For all the wheels, the bottom spokes are less stressed than the rest of the spokes (see Figure 6).

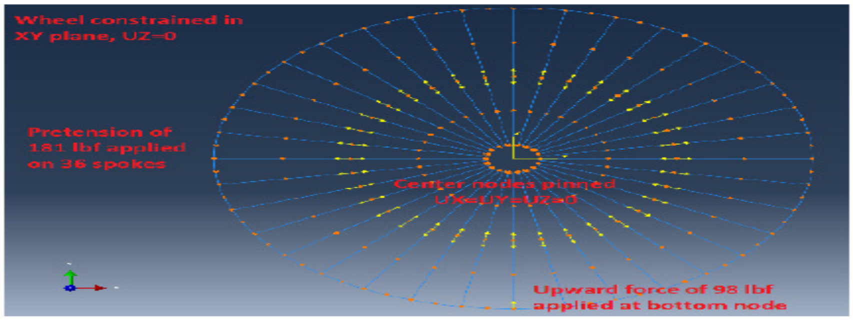

Figure 5: Loads and boundary conditions on a 36-Spokes bicycle Wheel created in Abaqus/CAE.

In other words, the spokes near the ground reduced in tension while the remainder slightly increased in tension. This is shown in Figures 8, 9, and 10, which plot the spoke tension due to preload against the spoke tension due to an additional load (radial load). The change in tension (difference between tension due to preload and tension due to a radial load) decreased with increasing number of spokes. Consequently, the more spokes added to a wheel, the greater its radial stiffness becomes. Another observation shown in Figure 6 is the deformation of all three bicycle wheels, scaled at 100 times magnification. The maximum vertical displacements occur at the bottom node where the radial load was applied (refer to Figure 5). The maximum vertical displacements of the bottom node decrease with increasing number of spokes (see Table 4). As a result, the radial stiffness increases because there are more spokes resisting the radial load. Table 4 also shows that the displacements due to preload are similar because the total pretension is the same for all the wheels. The displacements due to a radial load are small in comparison with the preload since the radial load is not as large as the pretension.

Table 4: Displacement for 28, 32 and 36 Spoked bicycle wheels.

Model	Pretension Per Spoke (lbf)	Total Displacement of Bottom Node (in)	Displacement of Bottom Node Due To Preload (in)	Displacement of Bottom Node Due to a Radial Load (in)
28 spokes	232	0.0131937	0.00913748	0.00405622
32 spokes	203	0.0127661	0.00906571	0.00370039
36 spokes	181	0.0124327	0.0090276	0.0034051

As part of the model checks, the sum of the reaction forces was taken at the center of wheel. The forces due to the radial load were approximately equal to 98 lbf. The forces due to preload added up to approximately zero lbf. There are three observations to make here: (1) As more spokes are added to the wheel, the stresses in the spokes decrease because there are more spokes supporting the compressive load; (2) In all the models, the lower spokes (not colored in red) are less stressed than the rest of the other spokes. The lower spokes have a reduced in tension while the remainder experience additional tension; (3) In all the models, the wheels have local deformation near the ground while
Maintaining an approximately circular shape.

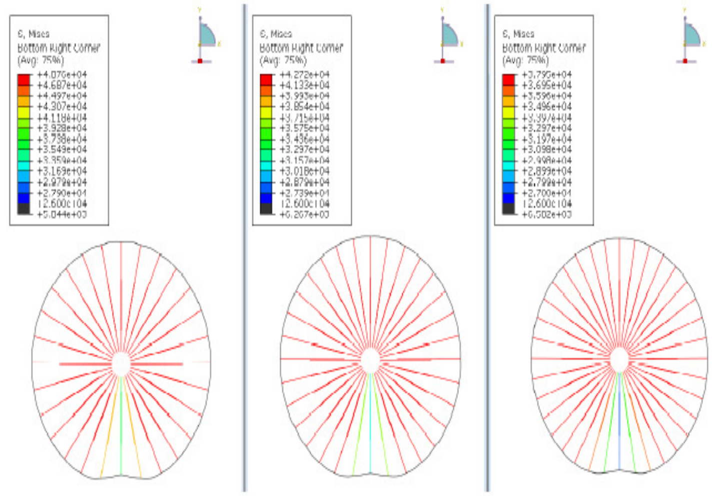

Figure 6: (Left to right) Stress plan of the 28, 32, and 36-spoked wheels at 100 times magnification

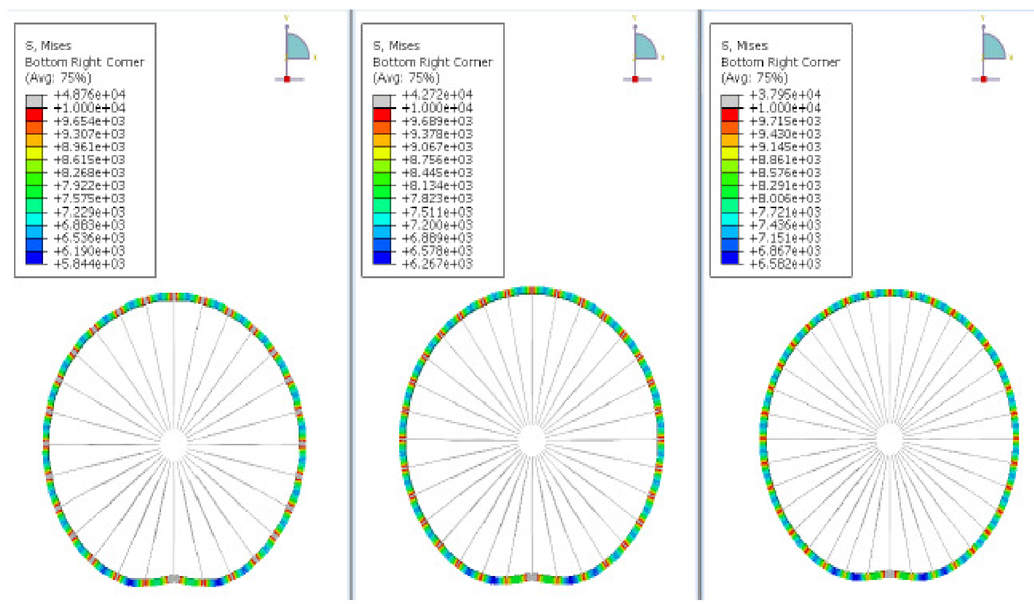

Figure 7: (Left to right) Compressive stresses of the rim for 28, 32 and 36-spoked wheels at 100 times magnification.

The plots show the compressive stresses for all three models as a result of the pretension spokes pulling the rim inward. For all the wheels, the maximum stresses in the rim occur at where it connects to the spokes. From left to right, the stresses decrease in the rim at where it connects to the spokes. This observation corresponds to the first observation made in Figure 6 where the spoke stresses decreased with more spokes added to the wheel. The data points for spokes 1, 2 and 28 are located below the preload line (colored in blue), which means that these spokes have reduced tension. Meanwhile the rest of the spokes have additional tension. (Bottom left) The reduced tension in spokes 1, 2 and 28 is represented negative here.

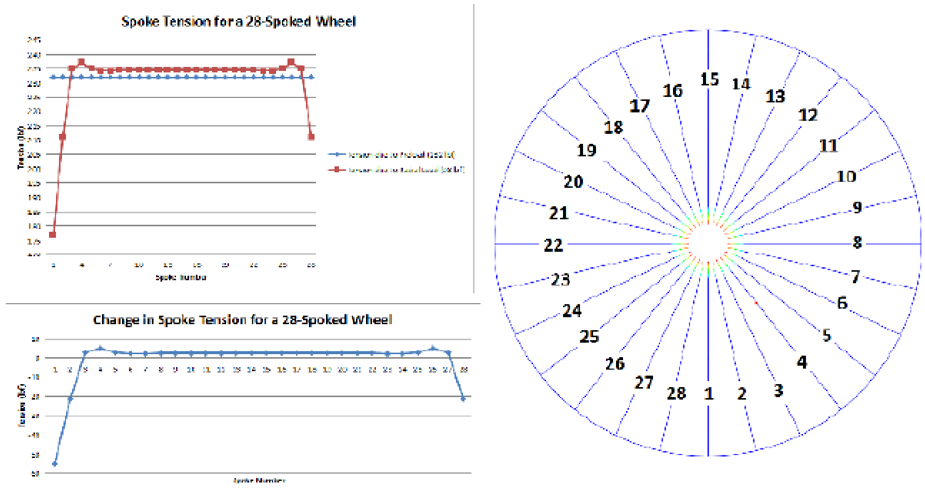

Figure 8: Plots of spoke tension and change in spoke tension for a 28-spoked wheel.

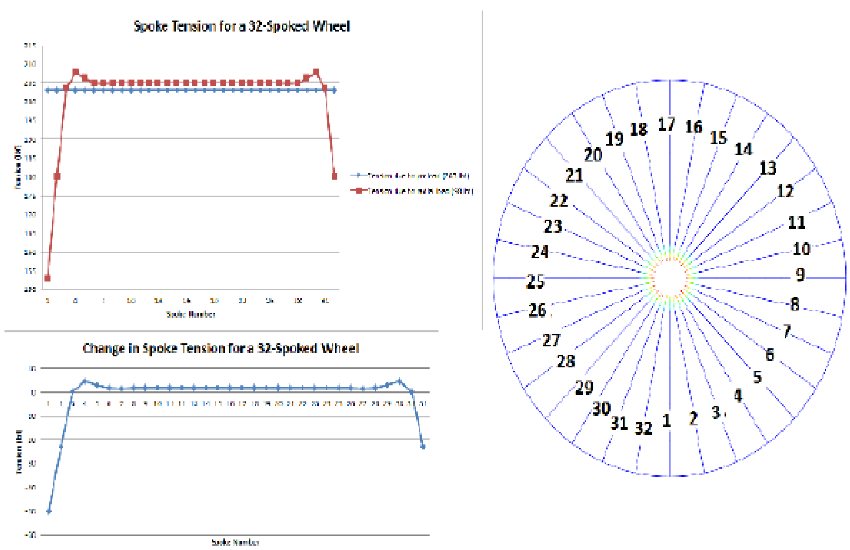

Figure 9: Plots of spoke tension and change in spoke tension for a 32-spoked wheel. (Top left).

The tension in spokes 1, 2 and 32 are reduced (their data points are located below the preload line). The tension in spokes 3 and 31 are the same as the preload line and therefore, experience no change in tension. The rest of the spokes have additional tension. (Bottom left) The reduced tension in spokes 1, 2 and 28 is represented negative here. The change in tension in spokes 3 and 31 are nearly zero. The additional tension in the other spokes is represented positive.

The tension in spokes 1, 2, 3, 35 and 36 are reduced (their data points are located below the preload line). The rest of the spokes have additional tension. (Bottom left) Negative change in tension means reduced in tension (see spokes 1, 2, 3, 35 and 36). A positive change in tension represents additional tension (see spokes 4 through 34).

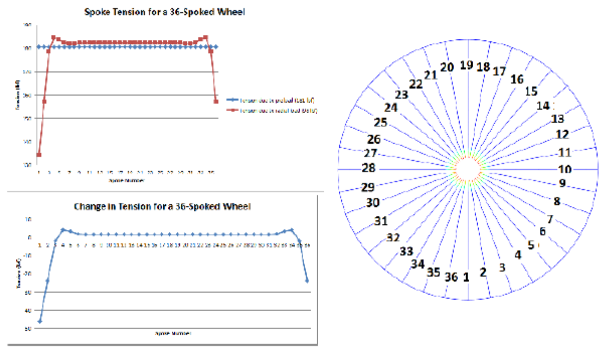

Figure 10: Plots of spoke tension and change in spoke tension for a 36-spoked wheel. (Top left)

4. Conclusion

This FEA project showed that the increasing number of spokes on a bicycle wheel increased the radial stiffness, as expected. The stresses and forces in the spokes and then displacements of the bottom spokes decreased as more spokes were added to the wheel. There were more spokes supporting the compressive load as well as resisting the load. The behavior of the 28, 32, and 36-spoked bicycle wheel models were in good agreement with the works. The models deformed locally at the point of contact with the ground while the rest of the wheel maintained a circular shape. Additionally, the lower spokes had reduced in tension while the rest of the spokes slightly increased in tension.

5. References

1. Bicycle Wheel. Bicycle Wheel Wikipedia: The Free Encyclopedia. Wikimedia Foundation, Inc. 2 July 2012, 4 Jul. 2012.
2. Brandt, Jobst, 2010. The Bicycle Wheel, Third Edition, 110-115 Avocet, Inc., Palo Alto, California 1981.
3. Brown, 2011. Sheldon.Frame Materials for the Touring Cyclist. Sheldon Brown-Bicycle Technical Information.Sheldon Brown.
4. Burgoyne, C.J. & R. Dilmaghanian, 1993. Bicycle Wheel as Prestressed Structure. Journal of Engineering Mechanics 119 (3), 439-455.
5. Lang, L.H, 2004.Hydroforming Highlights: Sheet Hydroforming and Tube Hydroforming. Journal of Materials Processing Technology 151(1-3), 165-77.
6. Peloubet, Don. Wheelmaking: Wooden Wheel Design and Construction.Issue 2, 68-74 Astragal Press, 1996.