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Design Control And Static Analysis Of Proposed A New Wheel Rim For Snowy Roads

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Abstract– In this study, a new wheel rim design and static analysis has been carried out to enable ground vehicles to navigate better in unfavorable road conditions such as snowy, icy and muddy. This new designed wheel rim has a dynamic structure. On roads with adverse conditions, the rods on the wheel rim move linearly, tangentially to the sidewall of the tire to reduce the tire's contact with the ground. In this way, the contact pressure applied to the ground by means of the rod increases and the vehicle moves in these unfavorable road conditions. Although this study is design-based in order to examine the usability of the designed vehicle rim, a static analysis was performed under 5.5 kN force on one rod. The force applied to the rim was determined considering a vehicle with a mass of 1000 kg. The static analysis was performed using two different materials for the rim and rods. As advances in material technology significantly affect the usability of this proposed new wheel rim. But still, while aluminum alloy was preferred for the body part of the designed wheel rim, an analysis study was carried out using titanium alloy in the rods on wheel rim.

Keywords : Wheel rim design; Finite element analysis; Adverse road conditions

1. INTRODUCTION

Wheel rims and tires are two important parts that affect the movements of land vehicles on the roads. The design of these two components significantly affects the road holding of the vehicles. Wheel rims provide to hold the tire. Dimensions and shape of the rim should be suitable to the vehicle. It is very common for the mechanical components of any system to be analyzed by computer before production (Stearns et al., 2006; Şik et al., 2015; Nithin Prasad, Hridin Pradeep and Anjish M George, 2017; Ekşi et al., 2018; Wan et al., 2019; Başyiğit, 2020; Çabuk, Yıldırım and Bakırcıoğlu, 2020). There are studies in the literature on wheel rim design and analysis. Dengfeng Wang et al. (Wang, Zhang and Xu, 2019) examined the wheel rim's fatigue, 90 ° and 13 ° impact performance, and performed united topology optimization based on a wheel rim structure design and they performed optimization method based on the performance. Wang and Xu (Wang and Xu, 2020) studied on fatigue failure analysis and multi-objective optimization for bolted / bonded magnesium-aluminum alloy mounted wheel. They showed that the fatigue life of spoke has reached more cycles than connecting bolts. Chang and Yang (Chang and Yang, 2009) were used nonlinear dynamic finite element to simulate a wheel impact test. They stated that, compared to real tests; The finite element results show that the total plastic working approach can be used to predict wheel breakage during impact testing. Gao et al. (Gao et al., 2019) modeled tires to investigate the effects of tire sizes and test methods on the wheel performance. They stated that the comparison between simulation and test results showed that the simulation methods presented could provide an effective way to assess the impact resistance of the wheel. Satyanarayana and Sambaiah (Satyanarayana and Sambaiah, 2012) studied about fatigue analysis of aluminum alloy wheel under radial load. Vijayakumar et al. (Vijayakumar et al., 2020) investigated a car wheel rim aluminum 6061 and 6066 alloys. They observed both static and dynamic analysis results, it was thought that the best material was recommended to make an effective rim structure. Xiao et al. (Xiao et al., 2014) proposed a topology optimization methodology where both fidelity and core frequencies were seen as static and dynamic optimization goals for the new steel wheel. As a result of the researches carried out, the design, analysis, etc. of vehicle wheels. While a lot of work has been done on it, there is no study on the design that provides a more functional use of the wheel rim.

So, in this study, a new wheel rim designed and analyzed statically. The new wheel rim be aimed to be used for ground vehicles on conditions with snowy and muddy road. Since this proposed new wheel rim model does not have a specific standard, approximate values are taken into account in the static analysis. However, it is predicted to give an idea about different academic studies.

2. MATERIAL AND METHODS

The proposed new wheel rim consists mainly of the rim body and electromechanical components. While the electromechanical component consists of a DC motor and a linear actuator, the rim body can be varied according to the preferred material. Besides, it needs a control system for the electric motor to work as desired.

2.1. Materials used in mechanical parts

Used materials effects on the strength, stability and life of the wheel rim. Similarly, changing the thickness of the wheel by a few can affect the properties of the wheel rim. Types of wheel rims are mainly three categories which are wire spoke, steel disc and light alloy. Especially, alloy wheels are the most

important used in recent years. Although, steel has high fatigue strength fuel consumption is more because of its weight. However, alloy wheel rims are excellent lightness. Alloy wheel rims are mainly aluminum, magnesium and titanium. Aluminum alloy has more lightness and reutilizing. So, Aluminum alloy's main advantages are mainly decreased weight, more precision and design choices of the wheel. On the other hand, magnesium alloy is lighter to aluminum. Besides, and also better as for size stability and impact resistance. Another prominent material, titanium alloy, has approximately 2-3 times more corrosion resistance and strength than aluminum, but costs more. (Gontarz, Pater and Drozdowski, 2012). Besides, composite material developed to low weight wheel rims. (Choudhary et al., 2016; Hwang et al., 2018). However, this wheel rims have inadequate consistency against heat and for best strength.

In static analysis, the effects of constant loading conditions on a structure are calculated by ignoring inertia and damping effects. Static analysis includes linear and nonlinear variables. In nonlinear analysis, materials can have plasticity, stress hardening, large deflection, large strain, flexibility. In linear analysis, the structure returns to its original undeformed state. Based on some hypothetical, linear analyzes are performed. First, displacements are linearly dependent on the applied load, secondly, the relationship between stress and strain is linear, and finally, the changes in geometry due to displacement are neglected as they are small. In nonlinear static analysis, large deformations may occur in the structure. Load-displacement relationships are generally nonlinear. The stress-strain relationship is represented by a nonlinear function (Choudhary et al., 2016).

Basically, two methods are used in the testing of rims, bending and radial (Firat et al., 2009; Previati et al., 2019; Ballo et al., 2020; Saxena, Jain and Pradhan, 2020). While the bending test is carried out to examine the effect of the centrifugal force on the rims caused by the movement of the vehicles in bends, the radial test is performed to examine the effect of the mass effect of the vehicle on the wheels. Radial tests are performed both under static load and as impact. The impact load is applied to the rim flange of wheel. This load is applied at two different angles, 13 and 90 degrees. However, in this study, static analysis was carried out with a slightly different method from those mentioned above, since it was not in standard wheel rim design.

Another important issue regarding the wheel rims is the material used. The materials used in the production of rims and their components can vary. According to this variety, both the weight and the mechanical strength of the rim vary. In this design-based study, two different materials are used to perform static analysis. While aluminum 6061 alloy, which is widely used in the industry, is preferred for the rim body, titanium Ti-6Al-4V alloy with higher mechanical strength is used in the rods (Mines, 2004; Zhou et al., 2017). The mechanical properties of these two materials are given in Table 1.

Table 1. Mechanical properties of the materials

Parameters	Aluminum 6061 alloy	Titanium Ti-6Al-4V alloy
Density	2700 kg/m^3	4500 kg/m^3
Tensile strength	310 MPa	1050 MPa
Yield strength	276 MPa	827 MPa
Shear strength	207 MPa	550 MPa
Fatigue strength	96.5 MPa	510 MPa
Elastic modulus	68.9 GPa	114 GPa
Poisson's ratio	0.33	0.34

2.2. Electromechanical components

The electric motor and the linear actuator are an electromechanical system as a whole. The appropriate electrical energy applied to the electric motor enables the motor to make rotational motion. As can be seen in Figure 1, this rotary motion is converted into linear motion by a transmission mechanism [1].

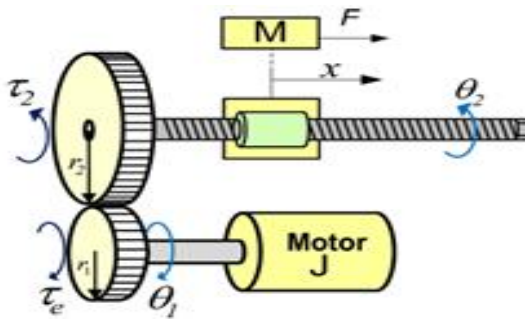

Figure 1. Free body diagram of electric motor driven linear actuator.

Here, τ_e and τ_2 are the motor output torque and the torque acting on the linear actuator, respectively. Similarly, θ_1 and θ_2 are the angular positions of the electric motor rotor and the shaft driving the linear actuator, respectively. *J* is the moment of inertia of the rotor and *x* is the displacement of the linear actuator, while *F* is the force produced by the linear actuator. *M* represents the mass of one of the rods mentioned in the rest of the study. When frictions are ignored, the relationship between motor torque and force of linear actuator can be associated with the following equations (Mao et al., 2016).

$$\tau_e = J\ddot{\theta}_1$$

$$\tau_2 = \tau_e(r_2/r_1)$$

$$F\dot{x} = \dot{\theta}_2\,\tau_2$$

3. PROBLEM STATEMENT AND DESIGN OF THE WHEEL RIM

One of the important parts of land vehicles to move safely is their tires. The lack of sufficient tires on these vehicles can cause problems especially on snowy or muddy roads (Hou, Chen and Chen, 2019). There are some commercial products called winter tires and snow tires designed to reduce the impact of these adverse conditions. Except this, by using some apparatus attached to the tires, it can be ensured that the vehicles progress in such adverse road conditions. Some application examples are given in Figure 2.

Figure 2. Some commercially available products

However, in case the adverse conditions are over, these apparatuses must be removed from the tire. Otherwise, both comfortable travels cannot be provided and these apparatuses are damaged. In order to eliminate these negative effects, a new dynamic wheel rim design has been proposed within the scope of this study as seen Figure 3.

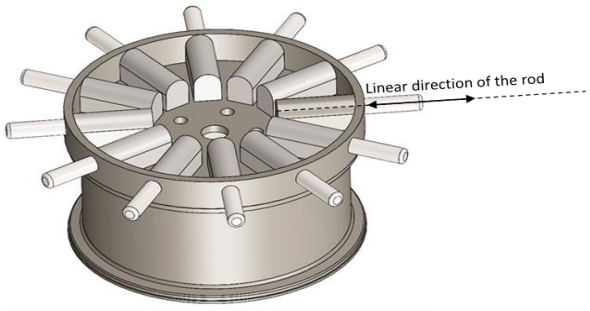

Figure 3. Mechanical model of the wheel rim and the direction of movement of the rods

The solid model of the rim design realized within the framework of these criteria is shown in Figure 4.

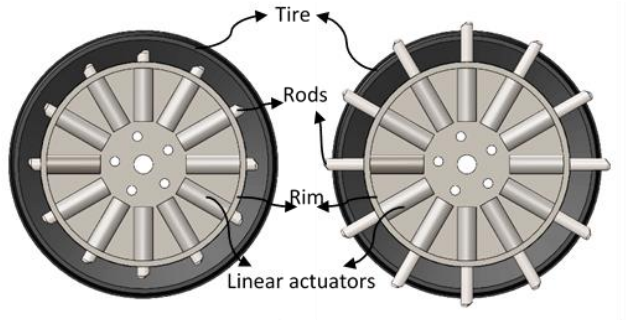

Figure 4. Designed new wheel rim solid model with tire

Different sizes of rims for different vehicle types or different sizes for the same vehicle type can be produced. The production of these rims is at the initiative of the manufacturer, provided that the mechanical strength conditions are met within certain standards. Although the new wheel design, whose static analysis will be carried out within the scope of this study, is not exactly made by observing a standard, the dimensions of the commercially available wheels are taken into consideration. Physical properties of wheel rim and rod are given in Table 2.

Table 2. Physical properties of the wheel rim

Parameters	Value
Rim Diameter [mm]	425
Rod Diameter [mm]	25
Rim mass [kg]	13.7
One rod mass [kg]	0.3
Rim width [mm]	225
Rod length [mm]	150

4. CONTROL METHOT OF THE SYSTEM

The rods connected to the linear actuator driven by a direct current motor moves linearly and passes the tire level. Thus, the contact of the spinning wheel with the ground is reduced. Thanks to the rods in contact with the ground, the wheel spinning ends and the vehicle can move. With the end of the adverse road conditions, these rods can move against the previous one and the vehicle can continue to move on the tires. The commands for this movement of the rods are given by the driver from inside the vehicle. In order for this proposed new wheel rim model to be fully used in a vehicle, studies should be carried out on various improvements regarding the linear actuator, battery system, control system and mechanical structure of the wheel rim. The design criteria determined in the initial form of this new wheel design are given below.

- It should be able to ensure the movement of the vehicle in adverse road conditions such as snowy, icy and muddy conditions.
- When the adverse road conditions are over, the tires should be able to keep the vehicle moving.
- The mechanical components of the wheel rim must have sufficient strength under possible loads.

5. STATIC AND FATIQUE ANALYSIS OF THE WHEEL RIM

Finite element method is a numerical procedure-based method to find solutions to many problems encountered in engineering. In this method, the area on which the analysis is studied is divided into simple geometric shapes called finite elements and divided into a series of finite elements. Material properties and management relationship are handled through these elements. In the method, an assembly operation that takes into account the required loading and constraint results in a series of equations (Stearns et al., 2004; Choudhary et al., 2016; Chen et al., 2017; Zakaria et al., 2018). The finite element model of the designed wheel rim is given in Figure 5. The results obtained from the static analysis affect the mesh

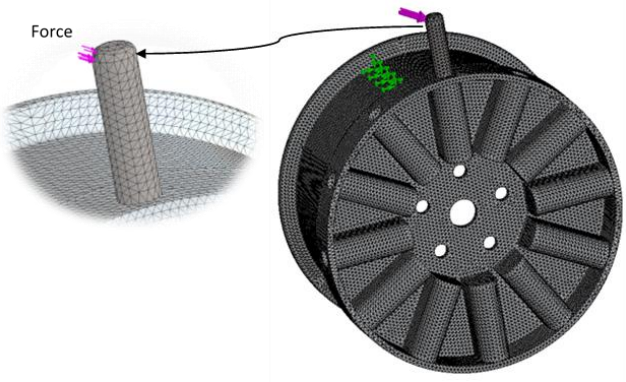

Figure 5. 3D Finite element model of the wheel rim

parameters of the created model. At the same time, relatively reasonable mesh parameters were determined as the mesh parameters affect the time to perform the analysis.

The angle of application of the force to the rods and the value of the force significantly affect the mechanical effects on the rim and especially on the rods. In this analysis, this angle was determined as 60 degrees. As this angle, which can be 90 degrees at most, increases, the deformation in the rods will increase. For vehicles with different masses, different values of force can affect these rods. Since a four-wheeled vehicle model with a mass of 1000 kg was envisaged in this study, taking into account the safety factor, it is assumed that a force of 5.5 kN affects the rod on the wheel rim.

4.1. Results and discussions

In the static analysis of this new wheel rim designed, the stresses, strains and displacements in both the rim and the rod with the effect of this force were investigated. The results obtained were evaluated by considering the mechanical properties of the materials used in the wheel model, given in Table 1.

The stresses occurring in both the rod and the rim are given in Figure 6. As expected, the highest Von mises stress occurred at the part where the rods contact the rim. This stress value of 280 MPa formed in rods is below the critical value for titanium alloy material.

As a result of the static analysis, the deformation in the rod is given in Figure 6. As expected, the maximum deformation under the applied force is at the tip of the rod and its value is approximately 0.68 mm. It should not be forgotten that these

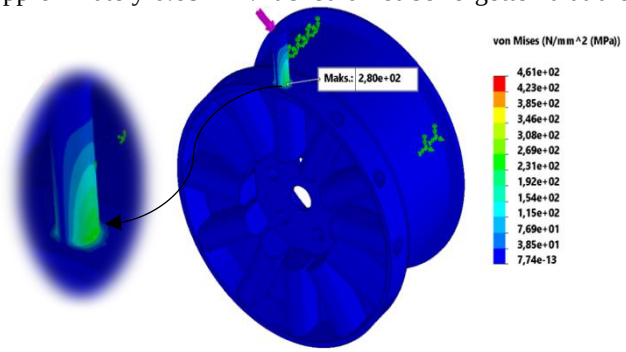

Figure 6. Von Mises stress of the wheel rim and rod

values may change on rims of different physical dimensions and rims using different materials. Similarly, this deformation that occurs in analyzes where different forces are applied will change.

5. CONCLUSION

In this study, where an unconventional wheel design proposal was presented, the static analysis of this wheel was also performed. Experimental studies should be conducted in order to reach a complete conclusion about the applicability of the study based on design. In addition, static analysis using different physical dimensions and materials with different properties, although not experimental, will be useful before the application. The vehicle mass accepted in performing the static analysis and the force applied accordingly may vary according to different vehicle types.

As a result, the results of the analysis performed within the scope of this study are significantly influenced by the physical properties of the wheel, the preferred material and analysis parameters. For this reason, it is thought that studies that examine these three conditions more comprehensively will be guiding about the applicability of this wheel model.

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