Design and analysis of hybrid reconfigurable wheel for armoured vehicles

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Abstract. The armoured vehicles are designed to carry heavy loads and move along a variety of terrains. The mobility is the major factor that makes the armoured vehicle move freely and rapidly over the terrains. Currently wheeled vehicles and tracked vehicles are used for off-road conditions. This paper a new hybrid reconfigurable wheel has been designed and analyzed that combines the benefits of the wheels and tracks. The reconfigurable wheel contains triangular configuration and circular configuration which automatically changed with respect to the speed of the vehicle. The triangular configuration will give more traction and stability while the circular configuration will provide easy mobility. In this paper, the various components required for the proposed mechanism are designed using CATIA V5 R6 and detailed stress and displacement analysis are carried out using ANSYS R18.2. The optimum design parameters are obtained and simulation of the reconfigurable wheel is performed. The reconfigurable wheel takes a triangular configuration when the speed is below 20kmph and transformed into circular configuration while the speed increases beyond 20kmph which assures stability and mobility of the armoured vehicle.

1. Introduction
Over the past decade the revolution and innovations has been evolved to gain the traction in the armoured vehicles but still the speed will not attained for the armoured vehicle. This ideology of the hybrid reconfigurable track-wheel mechanism in armoured vehicle ensures the traction and speed of the wheel. This configurable wheel proves more control and speed in off-road and mud tracks. This mechanism shows and proves that the wheel acts both track and wheel with respect to input speed. In this mechanism at low speed and high torque the wheel works as in the form of track at the same time for the high speed it works normally as wheel. This mechanism confirms the stability and high durability of the vehicle over off-road and irregular terrains. This principle and mechanism can be widely used in military wheeled vehicles, machine carrying wagons, gun carrying machines, military off-road vehicles, and heavy defensive machines for quick action. Reconfiguration of the locomotion is materialized by a different reconfiguration system, which consists of an actuating system, a pair of symmetric reconfigurable frames that are ingrained in three geared track wheels. The mechanical and electronics principles are used in the proposed configurable wheel. Y.G. Kim et al. [1] developed a driving control system for a mobile platform with wheel-track hybrid system for rough terrain for the civil environment. J. S. Dai et al. [2] used the reconfigurable mechanism for the robot control system. J. S. Dai et al. [3] introduced Mobility in metamorphic mechanisms for foldable kinds. S. K. Lim et al. [4] tried a new system for varying geometry with single-tracked mechanism for robot. K. Srinivasa Rao et al. [5] developed a new alloy wheels and carried analysis using analysis software. Miroslav Demić et al. [6] designed the steering system to minimize the kinematic errors. In order to eliminate the kinematic error, they proposed one new method with reduced wear. Andrzej Wiśniewski et al. [7]
collected the information about wheeled armoured vehicles and compared to get better future development. N.Rishi Kanth et al. [8] designed a crawler robot to climb, transportation, rescue and suit for deferent working places. This reduced the requirement of more information to run the robot. Aliakbar Alamdari et al. [9] introduced an analytical approach to modelling, analysis and reconfiguration of articulated leg-wheel systems. This approach increased the traction and stability margin. T. Maneewarn et al. [10] conducted a kinematic analysis for task-based reconfiguration of wheel-arm robots.

2. Methodology for hybrid wheel

The methodologies of the hybrid wheel-track mechanism used in the armoured vehicles and heavy vehicles explain that the proposed reconfigurable wheel will act as a track at low speed and wheel at high speed. The speed of the wheel has been sensed by sensors and if the input speed is less than 20Km/hr the hybrid wheel will act as a track and if the input speed is more than 20km/hr the track has transformed to a wheel. This mechanism works with respect to the speed and torque produced by the gearbox's output shaft. The hybrid wheel ensures the vehicle's durability and stability of the wheel over off-road and unpredictable terrains. These hybrid wheels consist of an actuating system and two symmetrical reconfigurable frames. To make a triangular shape for track mode three gears are used and also ten different gear shaped teeth that are meshed with rollers during track mode. To form circular shape these three gears are meshes with internal gears and the shaft meshes with the mainframe during the circular mode to rotate the whole wheel.

3. Design specifications

The proposed hybrid reconfigurable wheel consists of different parts to form the triangular shape and circular shape. Mainframe-in, Mainframe-out, Piston, Wheel, Roller, Drive shaft and Toggle gear are the parts used in the proposed hybrid wheel. The mainframe-in is the main component of the hybrid wheel that acts as a chassis in the configured wheel. Mainframe-out is another major component in the hybrid wheel that receives power through the driveshaft from the gearbox and transmits output power when the wheel is in a circular configuration. The mainframe's inner gears are used to convert the wheel from track mode to wheel mode. Steel 1020 are the material used the mainframe in and mainframe out.

![Figure 1. Exploded view of the parts used in reconfigured wheel.](image-url)
The Piston plays a major role while converting from triangle shape into a circular shape with the help of hydraulic actuating system. This actuating system drives the mainframe up and down and it is made up of Al 2025. The piston is used in six different places with same design and material. The arm is the component used to modify the tire's shape. This arm is coupled with the mainframe-mounted piston and spring and this system facilitates the rotation of the tires. Totally there are 12 arms used with the same material and design. While the shape is triangular, the roller is used to transmit power tangentially to the tire. The toggle gear is used to transfer power with free rotation from the drive shaft to the roller. The roller has no constrain about direction of rotation. Six toggle gears are used with same specification and material. This shaft is used to distribute power to the wheel from the gearbox. All the parts are designed based on the engine standards. Figure 1 demonstrates all the components related to hybrid wheel.

All designed parts are assembled together that will show as a front and isometric view of the configured wheel for circular and Triangular position in figure 2a, figure 2b and figure 3a and figure 3b respectively.

**Figure 2a.** Front view of the circular configuration.  
**Figure 2b.** Isometric view of the circular configuration.  
**Figure 3a.** Front view of the Triangular shape.  
**Figure 3b.** Isometric view of the Triangular shape.
4. Working principle of hybrid Wheel

Figure 4 shows the track configuration of wheel for the speed less than 20 kmph. During the working, the Piston will elongate towards the outside and arm will contract towards the inside to form a triangular shape. This Configuration of the wheel can sustain speed up to 20 kmph. The output of the transmission system is connected to the wheel through the driveshaft to drive the vehicle. The output of the driveshaft is connected to the mainframe-in. The mainframes were connected with a hydraulic piston arm to move up and down while the leg is constrained to the piston and mainframes. The up and down motion of the piston will shift the wheel shape from circular to triangular. The position of the arm adjusts automatically when the piston in the mainframe is pushed up using the hydraulic system. The roller is used for moving the layer in triangular locomotion. The roller is meshed for rotation in the same direction using the toggle gear connected between the driveshaft and the roller. The entire frame is rotated in circular locomotion by keeping the layer constrained. The piston in the mainframe will be pulled back and the arm will change the shape of the wheel to circular in shape. The output of the drive shaft is connected to the wheel and the wheel will rotate continuously. The speed of the rotating wheel was calculated using a sensor, in order to monitor the motion of the wheel. This sensor plays an important role in shifting the configuration from one shape to another shape. The shape of the wheel configuration was changed according to the speed of the wheel. If the speed of the wheel is less than 20 kmph, the configuration is track mode to initially gain traction, and if the speed is above 20 kmph, the configuration changes the shape into wheel mode.

Figure 4. Track configuration for the speed less than 20 kmph.

Figure 5 shows the track configuration of wheel for the speed above 20 kmph. If the speed increased above 20 kmph, the shape of the wheel was changed to circular from triangular. This circular design is obtained after action of piston contracting and arm extracting as same like the action happened in the triangular shape.

Figure 5. Wheel configuration for the speed above 20 kmph.
5. Result and Discussion

The parts are modelled using CATIA V5 software, and the analysis was carried out using ANSYS software (R18.2). For all parts associated with the configured wheel the structural analysis was performed.

Figure 6a. Displacement analysis on mainframe.  
Figure 6b. Stress analysis on mainframe.

Figure 7a. Displacement analysis on arm.  
Figure 7b. Stress analysis on arm.

Figure 8a. Displacement analysis on piston.  
Figure 8b. Stress analysis on piston.
Figure 12a. Displacement analysis on drive shaft.  
Figure 12b. Stress analysis on drive shaft.

Figure 6a and figure 6b illustrate the Mainframe displacement and stress analysis. In the mainframe, the maximum displacement and stress are $0.293 \times 10^{-6}$ mm and $2932.64$ N/mm$^2$. Mainframe failure begins when the load increases from the outer leg portion. The displacement and stress analysis of the arm is shown in figure 7a and figure 7b. $0.407 \times 10^{-5}$mm and $9177.15$ N/mm$^2$ are the maximum displacement and stress induced in the arm. The arm failure will occur due to the maximum displacement on the arm's outer edge. Figure 8a and figure 8b show the piston's displacement and stress analysis. The piston's maximum displacement and stress are $0.422 \times 10^{-5}$ mm and $9633.73$ N/mm$^2$. Displacement is the major factor in determining the piston's strength. Figure 9a and figure 9b demonstrate the mainframe displacement and stress analysis. In the mainframe out, the maximum displacement and stress are $0.123 \times 10^{-5}$ mm and $3096.3$ N/mm$^2$. The stress in the mainframe affects the mainframe out directly. The stress in the mainframe out is also greater than the stress in the mainframe. Figure 10a and figure 10b demonstrates the roller's displacement and stress analysis. The $0.148 \times 10^{-6}$ mm and $1319.4$N/mm$^2$ are the maximum displacement and stress induced in the roller. On the circular portion of the roller, the maximum displacement was achieved if the load increased from the material's allowable limit. The displacement and stress analysis of toggle gear are shown in Figure 11a and figure 11b. The toggle gear's total displacement and pressure are $0.334 \times 10^{-5}$ mm and $12879$N/mm$^2$. Gear is the highly affected part due to load. The major failure on the outer teeth was seen. The displacement and stress analysis on the drive shaft is shown in Figure 12a and figure 12b. The drive shaft's maximum displacement and stress are $0.334 \times 10^{-5}$ mm and $12879$ N/mm$^2$.

All the parts associated with the reconfiguration wheel, the displacement analysis were performed; the values obtained from the analysis are within the allowable value. The stress analysis also conducted for all the parts used in the triangular and circular configuration the stress values obtained from the analysis are within the allowable limits of the selected materials. The displacement values also within the allowable limits of the proposed materials.

6. Conclusion

The components used in the hybrid reconfigurable wheel for heavy-armed vehicle was modelled using CATIA V6 R9 and the parts are analysed using ANSYS R18.2 software. The components involved in the reconfigured wheel for both traction and wheel are subjected to displacement and stress analysis the values obtained from the analysis reveals that all the deflection values and stress values are within the allowable limits that will not affect the working condition of the system. This hybrid wheel concept is designed for heavy-armoured vehicles that carry artillery, armed weapons, missile carriers, combat vehicles, and other military-operated vehicles. This hybrid wheel ensures the vehicle's durability and stability of the wheel over mud and off-roads. The proposed wheel design offers both traction and speed of the wheel. The design and the working principle of the hybrid reconfigurable wheel are verified by running over a simulation using computer software.
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