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STUDY ON THE TRACK WHEELED VEHICLE DESIGNING FOR OFF-ROAD OPERATIONS ON SNOWY AND WET TERRAINS

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ABSTRACT. Off-road vehicle trafficking is of interesting subjects for agricultural, mining and civil engineering purposes. The traversing over snowy and wet terrain is of greater importance regarding the sinkage and terrain properties. The motion resistance, traction, sinkage, and vehicle stability are functions of wheel-terrain interactions and particularly the contact patch characteristics. As adoption of wheeled vehicles on snowy terrain is difficult, tracked wheel vehicles are of greater interest and applicability. In this paper, the designing and analysis of tracked wheel system mounted on a light weight all-terrain vehicle (ATV) is addressed. The designing considerations are based on semi-empirical models (Bekker and Mohr-Coulomb criterion) and experimentally obtained data on the snow mechanical properties for the test region. Based on the analysis, it is observed that the greatest value of total deformation for the front and rear chasses are obtained at 0.00028485 and 0.00026229 m, respectively. The von Mises yield criterion addresses that the yielding of materials starts when the second deviatoric stress invariant gets to a critical value close to failure. Furthermore, the greatest values of von Mises stress for the front and rear tracked wheel chassis are equal to 64.60 and 62.48 MPa, respectively. The similarity is that the critical point is situated at the coincidence point between the inclined and longitudinally oriented rods (joint point). It is concluded that the developed vehicle could serve as a functional vehicle to perform on different off-road operational condition particularly wet terrains.

Key words: Tracked wheel; ATV; Off-road vehicle; Snow.

INTRODUCTION

The context of terrain-vehicle systems has long been a dynamic field of studying interest for the researchers, vehicle designers and engineers. An extensive part of researches within this field are those corresponding the wheeled vehicle traversing on farmlands or for agricultural purposes (Taghavifar and Mardani, 2013; Coutermarsh, 2007; Kurjenluoma *et al.,* 2009). The theorem of wheel-terrain interaction was first established by Bekker

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(1969). The literature indicates that there are numerous factors and variables such as wheel and terrain properties that are determinant on the overall performance of the vehicle. Motion resistance is regarded as a negative factor applied to the wheel against the traversing direction that reduces the desired mobility of the vehicle. The type of wheel as single, dual, tracked, etc. is important on contact patch characteristics and thus on traction force provided by the vehicle. Tracked wheel is a system of vehicle propulsion in which a continuous band of treads is driven the corresponding wheels. The tracked wheels are less liable to be sunk in the soft terrain owing to the increased contact area. The vehicle weight leads to the lower sinkage since the contact pressure decreases at the greater contact patch. Therefore, tracked wheel vehicles take advantage of a low ground pressure and low motion resistance. The following gives a brief description of the studies undertaken associated with the tracked wheel vehicle traversing on off-road surfaces.

The tractive performance of wheeled and tracked vehicles was evaluated considering the differences between a tire and a track in generating thrust (Wong and Huang, 2006). A mathematical model was developed for the determination of the mechanical relationship between soil characteristics and the design factors of a tracked vehicle, and to predict the tractive performance of this tracked vehicle on soft terrain. On the basis of the mathematical model, a computer simulation program (Tractive Performance Prediction Model for Tracked Vehicles; TPPMTV) was also developed (Park *et al.,* 2008).

A detailed investigation into the effects of some of the major design features on the mobility of tracked vehicles over snow was carried out. The investigation was carried out using the latest version of an advanced computer simulation model of NTVPM. The obtained results indicated that the road wheel system configuration, initial track tension, and track width have significant effects on vehicle mobility over snow (Wong, 2009).

A 24-kg tracked robot was fabricated based on the performance of a 1400 kg manned vehicle scaled using Bekker mobility and then the mobility of the robot for 10 cases of deep snow and four cases of shallow snow was assessed. The results showed that a lightweight tracked robot performs well on deep-snow when ground clearance, motor torque (Lever *et al.,* 2006).

The study of track wheel-rough terrain interaction of light weight vehicle is presented in this paper. A proper system is investigated, developed, and evaluated so that the vehicle has the ability to traverse over snowy and wet terrain.

Terrain properties

It is well-known that terrain properties are determinant on the vehicle design, performance and mobility. Accurate measurement of snow physical-mechanical properties is an essential step for designing a proper wheel with the optimal performance providing enough traction and minimal sinkage. The tensile and compression tests were carried out by a digital cone penetrometer and shearing frame. A RIMIK digital penetrometer device (CP20) with tip cone angle of 30˚, a standard bar, a load cell and chipset, as shown in *Fig. 1*, were utilized to measure cone index. The tests were taken on a winter day, 2015, one day after snowing. The obtained results from the experiments are tabulated in *Tabs. 1 and 2.*

Figure 1 - Data collection on snow data

Table 1 - The pressure-sinkage parameters adopted from the experiments

Pressure-sinkage parameters	Values
n	1.01
k_c (kN/m^{n+1})	6.42
k_Φ (kN/m^{n+2})	1243.8

Table 2 - The shear strength parameters adopted from the experiments

Shear strength parameters	Values
c (kPa)	0.3
ϕ (˚)	31

Designing and development

In order to determine the optimal tracked wheel system, the identification of the system requirements with consideration given to the terrain properties is essential. A prototype ATV 4 wheel motorbike vehicle of SUZUKI LT80 with 351.9cc engine volume and maximum output power of 19 kw at 7000 r/min was considered. There is a necessity to ascertain the contact area and the characteristics at which the traction and sinkage are provided. Mohr-Coulomb criterion and Bekker theory of pressure-sinkage relationship are developed for the traction and sinkage (which leads to motion resistance), respectively.

The mathematical equations developed for tractive parameters are semi-empirical based developed theorems first introduced by Bekker (1969). Bekker's theory assumes that the maximum shear stress, s, is governed by a Mohr-Coulomb criterion as following:

$$\tau = c + p\tan\varphi \quad [1],$$

where c is the cohesion and φ is the internal angle of friction within the snow. For fairly uniform track pressures, p is equal to the *W/2bl*, where *b* and *l* are track width and length, respectively, in contact with the snow.

A vehicle traversing over snow needs to compact the snow adequately to support its weight while this work of compaction in its essence forms the motion resistance theory and the Bekker's method takes advantage of a power law to predict the pressure-sinkage relationship for snow (Lever *et al.*, 2006):

$$p = kz^n \quad [2]$$

$$k = {}^{k_c}/_{b} + k_\varphi \quad [3]$$

In this manner, Eq. 4 is yielded by substituting Eq. 3 in Eq. 2 as following:

$$\frac{W}{A} = \left({}^{k_c}/_{b} + k_\varphi\right)z^n \quad [4]$$

Given the vehicle weight, *W*, and the width of wheel, *b*, and the snow properties adopted from the experiments, the contact area and the traction force at the obtained contact area are determined. In this manner, the designed tracked wheel is in accordance with the in situ condition.

From Eq. 4, the following substitutions are made given that the standard track belt width for rear wheel is 0.25 m and the average sinkage is 0.1 m on snow for tracked wheel ATV vehicles (Giesbrecht, 2011).

$$\frac{W}{A} = \left({}^{k_c}/_{b} + k_\varphi\right)z^n \rightarrow \frac{\left(\left(\frac{500}{4}\right)\times 9.8\right)}{0.25\times l} = \left(\frac{6.42}{0.25} + 1243.8\right)\times 0.1^{1.01} \rightarrow l = 0.40\,m \quad [5]$$

Now from Eq. 1, using the contact area, A, the following is obtained:

$$\frac{T}{A} = c + \frac{W}{A}\tan\varphi \quad [6]$$

Consequently and based on *Table 2*,

$$T = cA + W\tan\varphi = 0.3\times(4\times 0.1) + 4905\times\tan 31° = 2.947\,kN \cong 3kN \quad [7]$$

This is amount of traction force for four wheels and the traction force the vehicle can provide as the drawbar pull is about 3kN.

A tracked wheel system is composed of the sprocket, bearings, a chassis, drive wheels, connecting rods and ground wheels (road wheels) as illustrated in *Fig. 2.* It is noteworthy that the considered ATV vehicle is 4WD , thus, the inner diameter of the driving sprocket shaft matches with that of vehicle rear drive shaft as being equal to 2 cm and the mean diameter of the sprocket equals to 13.5 cm. The tangential force increases 6.75 times more when compared to the input vehicle drive shaft. The objective ATV schematic and the dimensions of the tracked wheel are demonstrated considering that the distance between the front and rear axles as well as the axle height presented in the figure are based on the actual vehicle measured values. As abovementioned, the contact lengths are based on the calculations and the design considerations for the local snow condition. It is also worth noting that since the front wheels are driven, the wheels are not producing any traction term and so that the contact length is considered lower than the rear wheel so that the motion resistance force is reduced. *Fig.* 3 is dedicated to show the side and top view of the developed tracked wheel ATV vehicle based on the computed dimensions for the z system.

ANSYS R15.0 software was also adopted to assess the stress propagation and strength of the tracked wheel chassis since all of the dynamic loads and mechanical vibrations from the ground are exerted to the wheel chassis. The stress analysis and the total deformation under the loads applied to the system are influential on the stability and the final failure of the system.

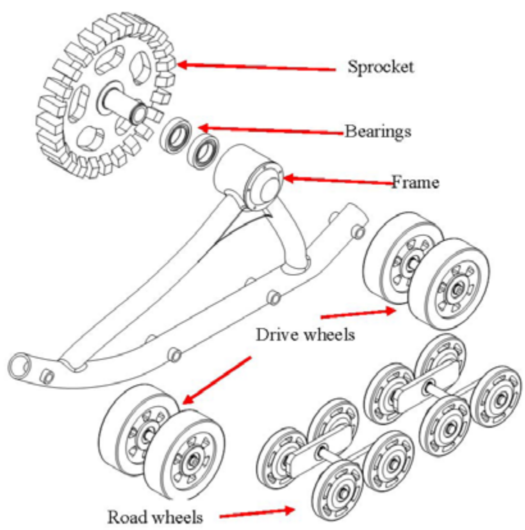


Figure 2 - Different parts and components of the developed tracked wheel system

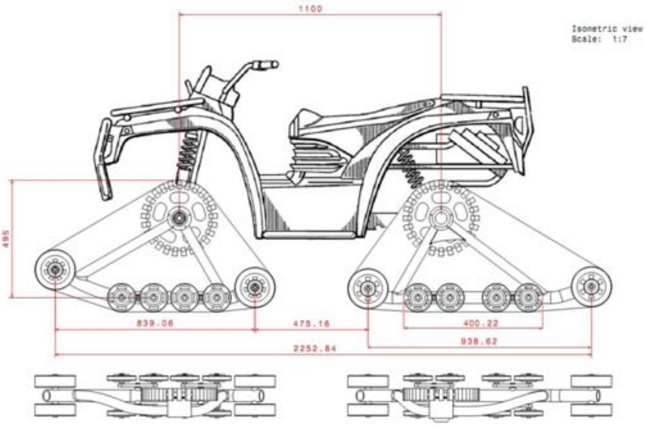
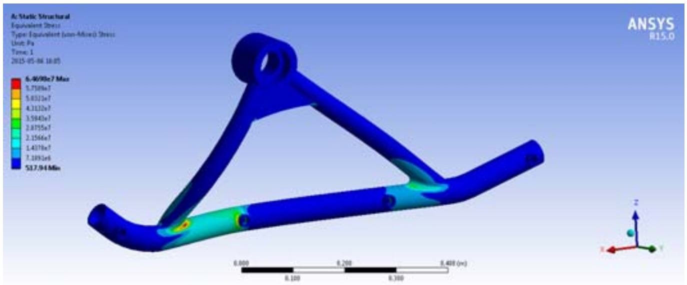


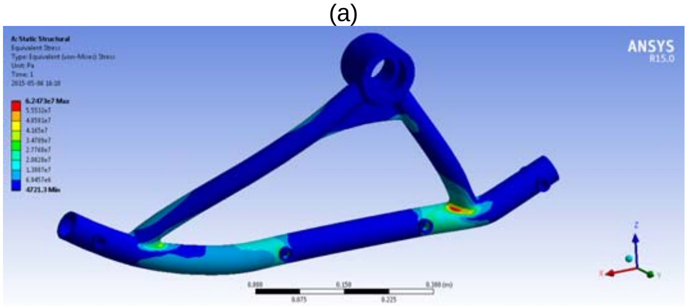
Figure 3 - The developed tracked wheel ATV vehicle based on the computed dimensions for the system

Fig. 4 is associated with the stress analysis (von Mises) results of the tracked wheel chassis for the front and rear wheels. The von Mises yield criterion addresses that the yielding of materials starts when the second deviatoric stress invariant gets to a critical value close to failure. The greatest values of v on Mises stress for the front and rear tracked wheel chassis are equal to 64.60 and 62.48 MPa, respectively. The similarity is that the critical point is situated at the coincidence point between the inclined and longitudinally oriented rods (joint point). Theses sections are substantial for the strength of the material and from the safety factor point of view. The total deformations of the chasses are shown in *Fig. 5*. At the greater distance from the center of axle, the deformation decreases while the greatest amount corresponds to the center of driving shaft connection housing. It is observed that the greatest value of total deformation for the front and rear chasses are obtained at 0.00028485 and 0.00026229 m, respectively. Deformation is the transformation of a body from a reference configuration to a current configuration. Although the deformations are small, any mechanical system with the elastic behavior and a mass subjected to the dynamic load functions as vibrating system and the deformations are thus important to avoid unwanted vibrations and creating ride comfort.

The results show that the developed system is able to create sufficient traction force with the minimal sinkage that enables the prototype ATV tracked vehicle to traverse over snowy terrain. The developed system is localized and optimized with the condition of the test region. The structural analysis with attention given to the strength of the chassis shows that the vehicle has functional and promising application with a minimal amount of total deformation.

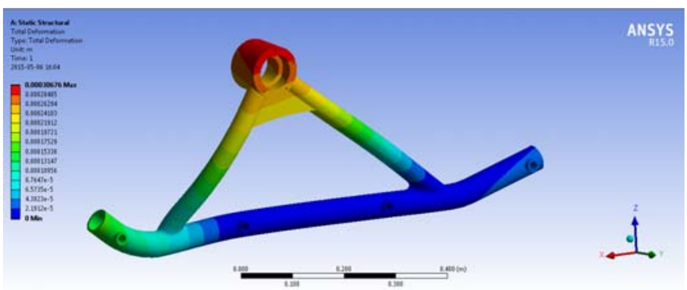


(a)

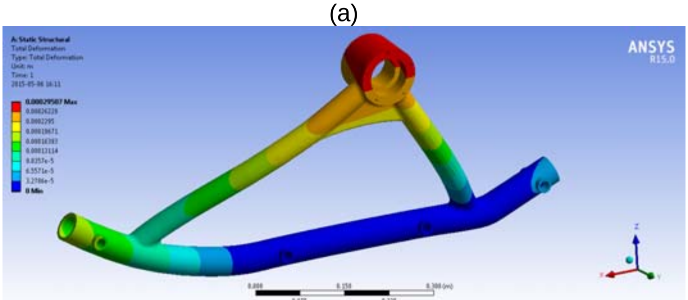


(b)

Figure 4 - Stress analysis (von Mises) results of the tracked wheel chassis for the a) front and b) rear wheels



(a)



(b)

Figure 5 - The total deformations results of the tracked wheel chassis for the a) front and b) rear wheels

CONCLUSIONS

Off-road vehicles are of dynamic fields of studying interest because of their various uses and versatility. The traversing over snowy and wet terrain is of greater prominence given that the terrain properties are more complex and nonlinear. The motion resistance, traction, sinkage, and vehicle stability are pivotal on wheel-terrain interactions and specifically the contact patch characteristics. Since the use of wheeled vehicles on snowy terrain is problematic, tracked wheel vehicles have better performance. The tracked wheel system evaluation mounted on a light weight all-terrain vehicle (ATV) is presented in this paper. The designing considerations are based on semi-empirical models (Bekker and Mohr-Coulomb criterion) and experimentally obtained data on the snow mechanical properties for the test region. Based on the analysis, it is observed that the greatest value of total deformation for the front and rear chasses are obtained at 0.00028485 and 0.00026229 m, respectively. Furthermore, the greatest values of von Mises stress for the front and rear tracked wheel chassis are equal to 64.60 and 62.48 MPa, respectively.

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