Research Article

Design and Fabrication of a Single Wheel Tester

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Abstract

A single wheel tester with the attention to the size of soil bin has been designed and constructed. The main part of single wheel tester include chassis, reduction gear unit, three phase AC electric motor, hydraulic cylinder, hydraulic tank, pump and valve, load cell and tires. Chassis is most important part of machine which was developed with the maximum value of Von mises stress, displacement and safety factor; 96.26 MPa, 1.48 mm and 2.597 respectively for 18.4 R 38 radial tire analyzed by ANSYS 12.1 software. The electrical motor and Ac motor speed controller had been used for changing the travel speed of wheel. The hydraulic cylinder had been attached to the machine to adjust normal force on tire.

Keywords: compaction; single wheel tester; soil bin; Finite Element; Von mises stress

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1. Introduction

Soil compaction mainly depends on the compression applied on the ground surface by agricultural machines. Hence, ground pressure at the soil–machine interface can be measured a good indicator of the potential compaction on agricultural soils [1]. Although with the increasing adoption of precision agriculture that can confine traffic, modern tractors are heavier and available power and their load carrying/pulling capacity is greater, hence, current field machines have potential to cause much more site disturbance and damaged [10]. The traction and flotation elements of agricultural vehicles, and the magnitude and distribution of their contact pressures at the soil surface directly affect the impact on the topsoil and its substrata. Optimization of tire operational parameters, to moderate and provide a uniform distribution of the contact pressure, is therefore important for the control of both top and subsoil compaction. To predict pressures in the soil caused by agricultural machinery, one has to be able to predict the pressure on the soil surface [8]. A sound mathematical model for the soil–traction communication process allows researchers to examine many problems related to tractor performance under a wide range of conditions with the goal to improve efficiency tractor operational parameters, to improve tractor design, and to improve the tractor/implement match. Comparative significance of these agents affecting field performance of a tractor can be attained without expensive field-testing. These models can also aid tractor operators to improve and efficiency their tractors arrangement to match operating conditions [13]. The influence of the tire dynamic load may result in a tradeoff between traction performance and soil compaction. The main goal of building a single wheel tester is to provide information about traction performance of tires, under known load and slip conditions, that can contribute to energy saving, environmental protection and control of soil compaction [12]. The effect of soil compaction was to be assessed by measuring soil displacement, changes to soil density and cone penetrometer resistance. Machines for operating a single tire in soil bins were described by Ansorg and Godwin, 2007; Chen, 1993; Kawase, Nakashima and Oida, 2006; Tiwari, Pandey and Pranav, 2010; Wells and Buckles, 1987 [2, 4, 7, 13, 15]. Single wheel traction research machines for operating a single tire in a field were described by Billington, 1973; Gill and Vanden Berg, 1968; Shmulevich, Ronai and Wolf, 1996; Upadhyaya et al., 1986 [3, 6, 12, 14]. A method for complete vehicle analysis established on Finite Element (FE) method was presented. This method is used for analysis of complete vehicle characterize such as vehicle dynamics and stability. Reza Moazed (2010) used experimental and numerical methods, for analysis Strength of welded Thin-walled Square Hollow Section T-joint Connections by FE. The results obtained by finite element method were verified by a photo-elastic stress analysis [9]. Ebrahimi et al., (2010) performed an analysis of a Hay Bale Trailer. Based on finite element analysis results redesign was carried out for the trailer for strength optimization [5]. The main goal of this research was designing a single wheel tester with the regard to the dimensions of soil bin and analysis of the chassis and the other part to reach the appropriate safety factor for fabrication to single wheel tester. This device (Fig. 1) can apply the vertical load, measured by the load cell, on the tire and then tire move ahead with the given
speed. Furthermore by a penetrometer the compaction of the soil in different part of the footprint of tire is measured.

2. Materials and Methods

This study was conducted in the Agricultural Engineering Research Institute (AERI), Iran with assistant of Biosystem Engineering Faculty, Tehran University, during June 2011 to May 2012. The device and its component were modeled in Part area of Solid Works 2010 software. Main parts of single wheel tester include chassis, reduction gear unit, three phase AC electric motor, hydraulic cylinder, hydraulic tank, pump and valve, load cell, torque transducer and tires. For designing the chassis of single wheel tester, AISI 1018 steel profiles were used (Fig. 1). The dimensions of the chassis were 3100 mm (length), 1900 mm (width) and 2230 mm (height).

![Figure 1. a- Exploded view of single wheel tester, b- Isometric view of chassis](image)

A reduction gear unit (reduction gear ratio; 1:52) was used for this design. The drive shaft was directly connected to the tire hub. The rolling resistance was calculated by Al-Hamed et al empirical equation (Equation.2) for radial type tire \[ B_n = \frac{Cbd}{W} \left( \frac{1 + 5\frac{s}{h}}{1 + 3\frac{b}{d}} \right) \] (1)

\[ \frac{T}{rW} = 0.88(1 - e^{-0.1B_n})(1 - e^{-9.5S}) + 0.032 \] (2)
By using the data from Table 2, a three phase AC motor was selected (Motogen 180L6; 15KW; 967rpm) that includes 148.2 N.m output torque and an inverter unit (Ac Motor Speed Controller, LS600) was added to control the motor revolution speed (Error! Reference source not found.b).

Table 1. Data for determining of rolling resistance

<table>
<thead>
<tr>
<th>d (mm)</th>
<th>b (mm)</th>
<th>C (MPa)</th>
<th>W (KN)</th>
<th>Δ</th>
<th>S (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1750</td>
<td>467</td>
<td>0.2</td>
<td>25</td>
<td>0.2</td>
<td>15</td>
</tr>
</tbody>
</table>

Table 2. Data of rolling resistance torque

<table>
<thead>
<tr>
<th>Tire type</th>
<th>T (N.m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial</td>
<td>7546</td>
</tr>
</tbody>
</table>

Vertical load on the wheel test may be varied by adding hydraulic cylinder to a rack fitted on top of the test wheel carriage. A hydraulic package with 70 bar pressure and 15 l/min discharges and one hydraulic valve were used for controlling the hydraulic cylinder which was attached to wheel tester. The required power of the package is a three phase ac motor (Motogen; 2kW) and a reduction gear unit (reduction gear ratio 2:3) (Error! Reference source not found.).

Figure 2.a- Reduction gear unit, b- Ac motor speed controller
The vertical load is measured by load cell (CLP-3B) with 30kN capacity and calibration graph and equation were obtained (Error! Reference source not found.).

After modeling of components in Solid Works 2010, mechanical analysis of these components was fulfilled using ANSYS software. Force and moment was inserted on components of chassis and plate by considering boundary conditions and physical and mechanical properties of construction material (Table 3). Weight of components was calculate by the software, depends on density and geometrical model.

Table 3. Physical and mechanical properties of steel AISI 1018

<table>
<thead>
<tr>
<th>Specification</th>
<th>Values</th>
</tr>
</thead>
</table>

y = 0.001x + 0.314

\( R^2 = 0.999 \)
The static analysis of chassis was fulfilled after several sensitivity analyses. The size of the finite model is nearly 36266 elements and 67486 nodes. After receiving the solution the results of analysis was reviewed using post processing to determine maximum induced stress and its location. In designing parts to resist failure, it is ensure that the inner stresses do not cross the strength of the material. If the material to be used is ductile, then it is the yield strength that designer is usually interested in, because a lasting deformation would comprise failure. The Von-Mises theory is the most appropriate theory to be used in ductile materials \(^{[11]}\). Von-Mises stress is calculated by using the equation.3:

\[
\sigma' = \sqrt{\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2}{2}}
\]

In equation 3, \(\sigma_1, \sigma_2, \sigma_3\) is principal stresses connected with the three principal directions. Factor of safety can be computed by dividing yield stress to maximum Von-Mises stress.

3. Results and Discussion

3.1. Chassis analysis

Results of chassis mechanical analysis are shown in Error! Reference source not found. and Table 4. Accepted safety factor was applied as to be 2.597 and it is appropriated for designing.
These results show that maximum stress is occurred in places of chassis having welding. Therefore, in order to strengthen this welding is necessary. Maximum deformation was occurred in top of the chassis. After mechanical analysis of components, primary single wheel tester was fabricated, as shown in Error! Reference source not found..
3.2. Characteristic

One of the advantages of this machine is to use fewer parts to provide wheel’s power in comparison to other single wheel tester. The largest tire overall diameter that will fit on the single wheel tester is 1880 mm and the smallest tire that will fit is 760 mm. The capacity of the normal load cell is 30 kN and the wheel angular velocity was sufficient to provide sliding velocities up to 2.1 rad/s. The single wheel tester has no capability for changing the steer angle of the wheel, so the wheel axis of rotation is always in the lateral direction. The lower end of the hydraulic cylinder has a rod end bearing attached and the upper end is rigidly mounted to load cell, so this arrangement allows the load cell to maintain proper alignment and minimizes any moments that the frame members might tend to apply to the load cell.

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Reference


