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Design, development and analysis of single wheel lab test setup using FEM

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Abstract

A single-wheeled lab test setup with the dimension of the existing soil bin (30 m x 2.3m x 1.0) has been designed, analyzed and constructed for testing and comparing the performance of the tires. The main parts of the lab test setup include the mainframe, chassis, gearbox, 3- phase AC electric motor, counterbalancing unit, guide rails, and tire. Chassis is the most important part of the lab test setup which was designed in Creo parametric1.0 and analyzed in Creo simulation 1.0 using the static Finite element method (FEM). Chassis were kept loaded with a 10 kN Normal load. Results revealed that maximum von mises stress, displacement, and strain; developed on chassis was 237.5 MPa, 0.856 mm and 8.56×10^{-4} respectively. The chassis design was observed to be satisfactory for fabrication purposes. All the other components fabricated were mounted over the chassis and lab setup was completed. The electrical motor, motor speed controller and gearbox mounted over lab test setup provides variable rate forward and backward speed. Additional weights were used for changing the normal vertical loads on the lab test setup. The tires with the specification of maximum overall diameter up to 70 cm and maximum width up to 45 cm can be accommodated on the lab test setup.

Keywords: FEM, creo software, single wheeled lab test setup, von mises stress, tires

1. Introduction

India's current population is 1.32 billion and it is growing annually at rate of 1.1% annually (World Bank, 2017). The biggest challenge in front of an agriculturist is to meet the food grain demand of the increasing population. High energy inputs, farm mechanization and better management practices can provide a solution to food grain problem. In India, current farm mechanization level is 2.02 $kWha^{-1}$ which is lower than the other advanced countries like Japan (8.75 $kWha^{-1}$) and Italy (3.01 $kWha^{-1}$) etc. Mechanization in India is mostly related to tractors, power tillers and self- propelled machineries. Machineries manufactured across India are mostly rear wheel driven. The driving wheels interact with the soil and develop traction which propels the machinery. Research study conducted by Burt *et al.*, 1982 showed that nearly 20-55% of the available engine energy is wasted at the tire-soil interface. This significant loss of power wears tires and results in soil compaction which is harmful for crop production. Soil compaction primarily is due to the vertical load applied on soil surface by agricultural machineries (Abou *et al.*, 2004) [1]. With the advancement in technology progressively, modern machineries are heavier, more powerful and there load carrying capacity is also greater. Hence, they have more chances to compact the soil, induce site disturbance and damaged the crop (Mohsenimanesh, A. and Ward, S.M. (2010) [12]. Tire design optimization for uniformly distributing the vertical load on soil surface can help to control top and subsoil compaction. There are various methods for measuring tires performance such as field method and laboratory method but laboratory performance measurement under control conditions is commonly used. Laboratory evaluation provides the controlled conditions; therefore individual parameters can be evaluated with greater accuracy. The main aim of laboratory wheel testing device is to extract information about traction performance of tires, under loaded conditions that can be helpful for saving energy, protecting environment and control soil compaction. Chen, 1993, Tiwari, *et al.*, 2010 [3, 10] and other researchers had developed, described the single wheel setup in soil bins. Gill and Vanden berg, 1968; Upadhaya *et al.*, 1986 [6, 11] and others had studied the tires performance using single wheel tester in soil bin. In this paper a method for complete design and analyzing the single wheel lab test setup for existing soil bin (30 m x 2.3m x 1.0) is presented which is based on Finite element (FEM). FEM is a numerical based approach for solving physical problems using differential equations. It discretizes the domain region, formulates equations, and solved them, and finds the variables of interest (Velloso *et al*., 2018). De *et al*., 2014 [13, 4] designed and analyzed coffee dragging device using FEM. Farhadi *et al.*, 2012 [5] design and constructed a single wheel tester consisted of chassis, hydraulic cylinder, reduction unit (gearbox), 3-phase AC electric motor, hydraulic tank, pump and valve, load cell and tire. Chassis is critical component of the system which was designed in Solid works 2010 and analyzed in ANSYS software using Finite Element Modeling (FEM).The maximum Von Mises stresses and maximum deformation were 96.26 MPa and 1.48 mm respectively. The main goal of this research study was to design, analyze and fabricate a single wheel lab test setup for testing tires.

2. Materials and Methods

This study was conducted in Division of Agricultural Engineering, ICAR- IARI, New Delhi and the system was fabricated in the Divisional workshop. The setup is initially geometric modeled in Creo–parametric 1 and analyzed in Creo simulation 1. The Components of single wheel lab test setup consisted of (Fig 1).Main frame and chassis, pneumatic wheels (Tires), acrylic sheet subsystem and guide rails for lab setup, motor, worm gear box, universal coupling, power transmitting chain and sprocket, counter balancing unit and pulley and drive shaft for carrying load of setup.

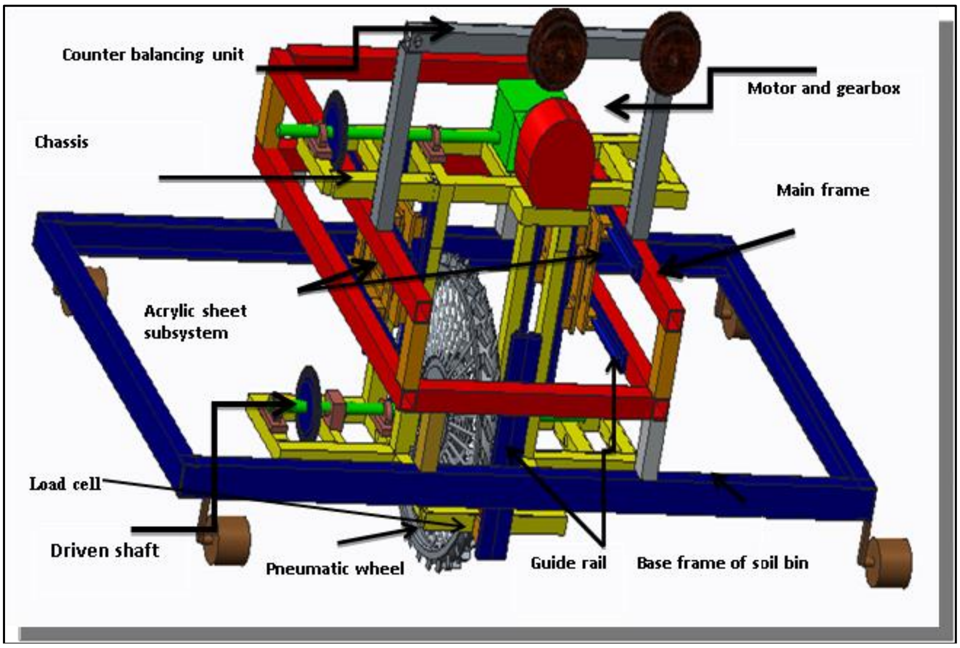

Fig 1: Computer aided design of laboratory single wheel test setup

2.1 Main frame and chassis for lab test setup

The Lab test setup consists of two frames 1) - main frame, 2)- chassis. For designing the main frame and chassis 45 x 45 mm hollow mild steel section with thickness of 3.2 mm were used. Size of main frame was 1.1 m×0.7 m (Fig 2a). While for chassis 0.90 m×0.45 m, the load was kept above the chassis. The chassis was provided with space to accommodate different tires (Fig 2b). Static analysis is carried out for chassis by creating meshing and providing boundary conditions.

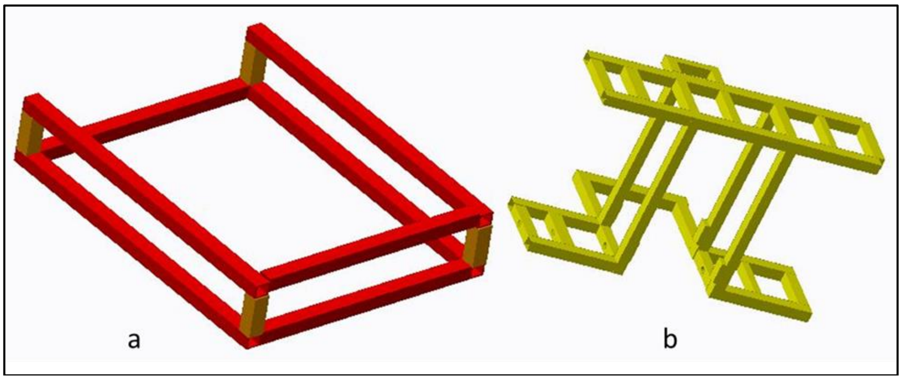

Fig 2: Computer Aided Design of Main frame and chassis

Table 1: Physical and mechanical properties of steel selected for main frame and chassis

Specification	Values
Yield strength	250 MPa
Density	7827Kgm^{-3}
Poisson's ratio	0.27
Young modulus	199.948Gpa

2.2 Tires for lab text setup

Tires with rim transfers the normal load from axle to the ground and develops traction force at soil-tire interface. The detailed specifications of the mounted tires are given in Table 2.Two types of tires are shown in Fig (4a) which were fitted on setup.

Table 2: Specifications of different pneumatic tires

SI No.	Tire size	Rim Dia.(mm)	Section width (mm)	Section Height (mm)	Overall Dia. (mm)
1	3”-17”	431.8	76..2	76.2	585
2	4”-18”	457.2	100	76.2	610

2.3 Acrylic sheet subsystem and guide rails for lab setup

The acrylic subsystem consisted of two squared acrylic sheets of size (250 x 250 x 12 mm), linear motion bearing of LTCF20 with size 50 x 48 x 13 mm made of zinc alloy. Total of 8 linear motion bearings on acrylic sheets (4 vertically and 4 horizontally) were mounted (Fig 3). The acrylic sheet sub-system was connected to the main frame of test setup through guide rails. The guide rails were of size 500 x 45 x 10 mm made of aluminum was selected for allowing the free vertical and horizontal movement to the lab test setup. The guide rails and bearings material were selected because of their longer life and precision work (Fig 4b.).

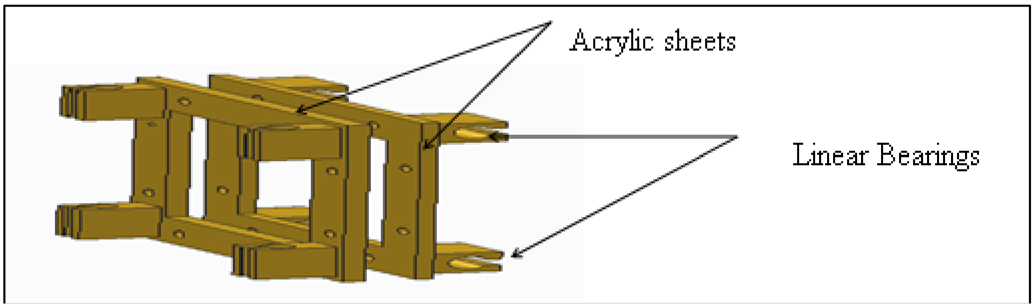

Fig 3: Computer aided design of Acrylic sheet subsystem.

2.4 Motor and gearbox for lab setup

The speed for operation of wheel was kept between (2-3 kmh^{-1}) i.e. (20-50 rpm**)** due to limitation of existing soil bin carriage**.** A three phase motor (5hp, 1430 rpm) was selected to operate wheels at different operating conditions. It was provided with a Delta VFD-M (3.7 kW, 460V 3phase) speed controller for regulating speed within a limit. Motor speed after reduction with controller was decreased through the gear box of reduction (30:1) and then by chain and sprocket. Speed Controller was mounted on chassis.

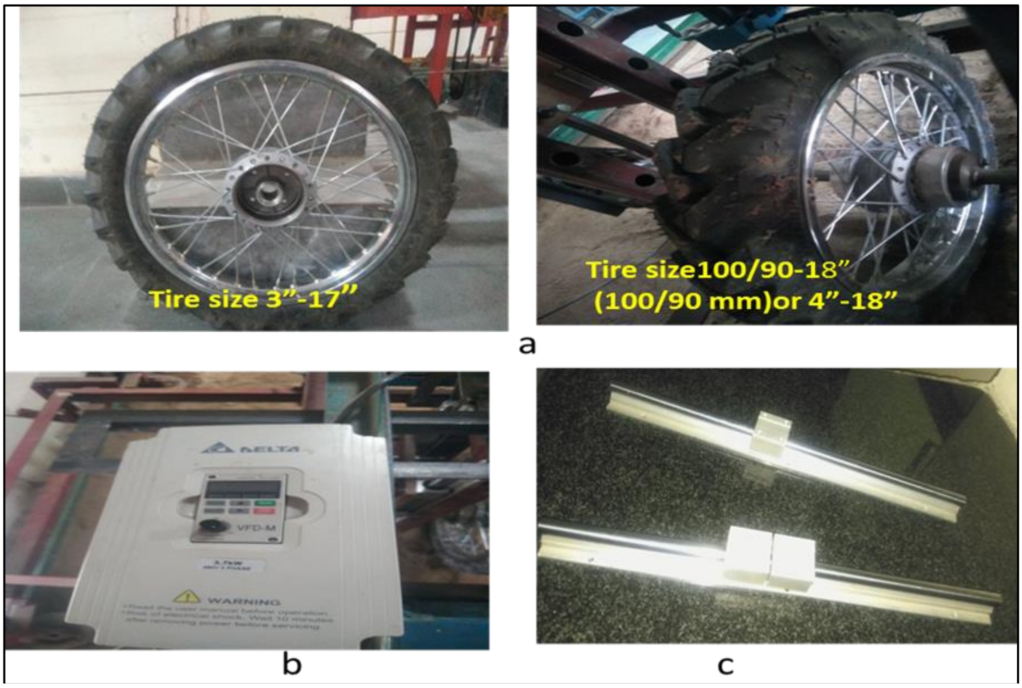

Fig 4: (a) Pneumatic tires used in single wheel test setup, (b) Guide rails and linear motion bearing, (c) Delta VFD-M speed controller

2.5 Power transmitting chain

A chain for power transmission from gear box shaft to driving wheel was selected on the basis of Equation 1.The sprockets with 20 and 36 teeth were selected to get desired speed of 1.5-3 kmh^{-1}. The center to center distance between two sprockets was kept 780 mm.Small sprocket having teeth (T1) =20, Large sprocket having teeth (T2) = 36

Total chain length was calculated from the formula given by: (Khurmi and Gupta, 2005) [8].

$$L = \frac{p}{2}(T1 + T2) + 2X + \frac{\left(\frac{P}{2}cosec\left(\frac{180}{T1}\right) - \frac{p}{2}cosec\left(\frac{180}{T2}\right)\right)^2}{X} \quad \ldots (1)$$

Where,

L = Length of chain, mm, P = Pitch of chain, mm, T1 = Number of teeth on drive shaft, T2 = Number of teeth on driven shaft, and x = Centre to Centre distance between two sprockets

2.6 Counter balancing unit

A counter balancing unit was fabricated consisting of two pulleys, wire and a frame (0.7 x 0.05 x 0.5 m) size, made of mild steel as shown in Fig 5. This was attached to the main frame through nut and bolts for neutralizing the weight of laboratory setup.

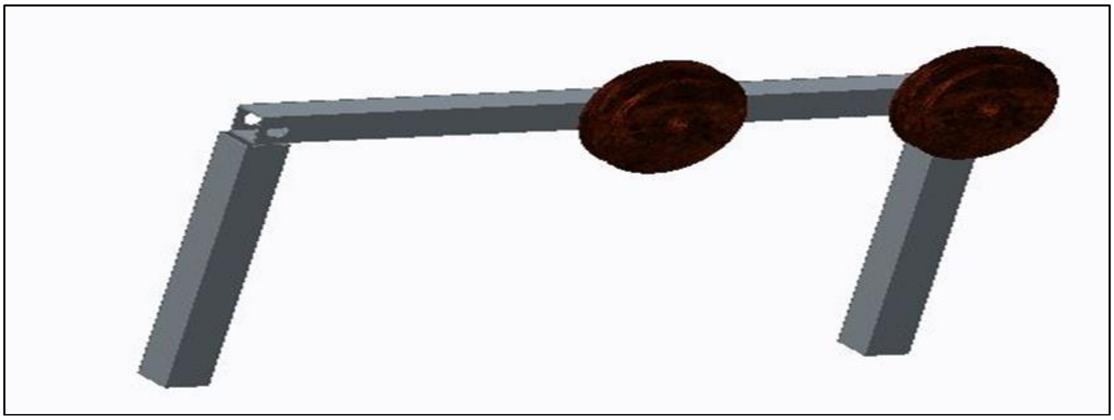

Fig. 5: Computer aided design of Counter balancing unit of lab setup

2.7 Drive shaft for power transmission

A shaft for transmitting power from driven wheel sprocket to ground was fabricated on the basis of Equation 2. Shaft design was done on the basis of total power supplied to the wheel by the motor. Max power to be transmitted by motor to wheel was 5 hp (at load condition) and motor rpm (N_0) was 1430 rpm. Desired speed for power transmission on drive shaft was 3kmh^{-1} which corresponds to 30 rpm for selected wheels.

$$\text{Power (P)} = \left(2\times\pi\times N\times\frac{T}{4500}\right) \qquad \dots 2$$

2.8 Meshing and Boundary conditions

Meshing is the discretization process in which chassis was divided into numbers of small elements. Chassis was loaded with normal load (external weights) 10kN kept on top of it. Meshing was created by setting local control of maximum element size kept to 10mm (Fig 6a & 6b).

2.8.1 Boundary conditions

Chassis was constrained by keeping the geometry fixed at the base (dotted blue points) and loaded at top (F_1= 9.81k N) and bottom (F_2= 0.19 kN) (orange arrows) as shown as in Fig (6c).

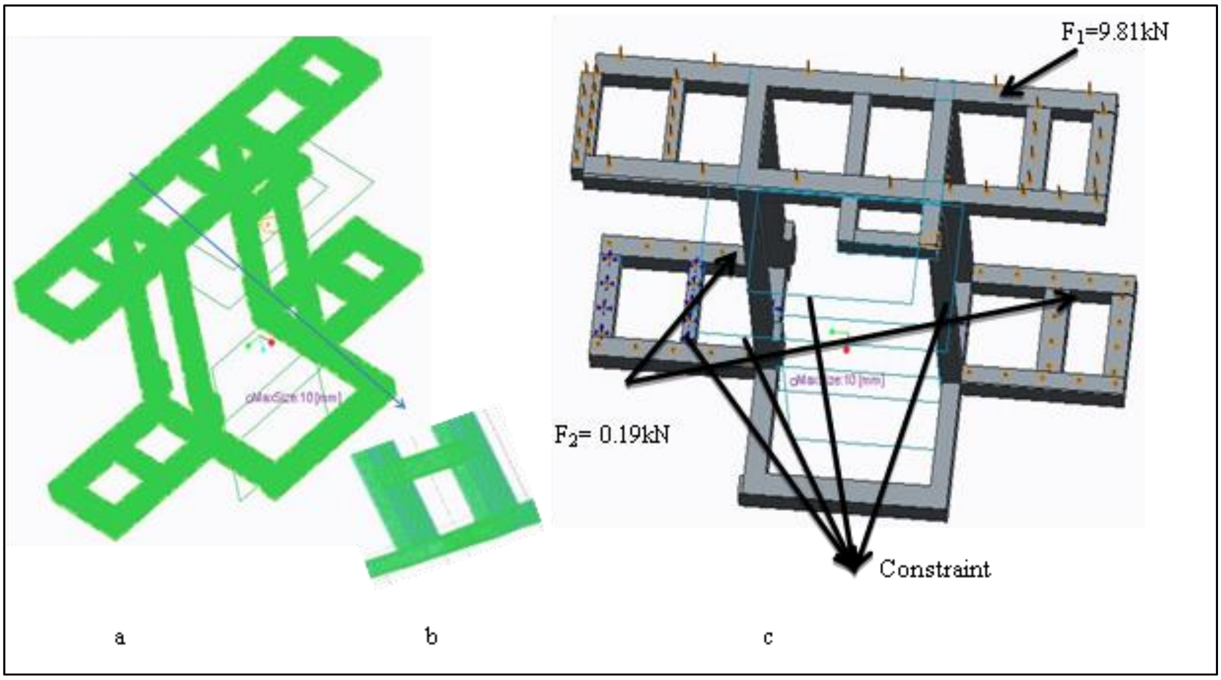

Fig. 6: Meshing and Boundary conditions for chassis (a) - meshed structure, (b) - Cross-section of meshed structure, (c) - Boundary conditions for chassis.

2.8.2 Static analysis

Static analysis of chassis was done in Creo simulation1. Stress, deformation and strain were obtained.

3. Results and Discussion

The results obtained from the static analysis of chassis were presented. Stress, deformation and strain were observed for given boundary conditions. Total number of elements and nodes produced were 187442 and 48015 respectively.

3.1 Stress Analysis

The maximum and minimum von mises stress developed was 237.540 MPa and 8.569×10^{-5} MPa respectively. Maximum stress developed in a place where welding was done (Farhadi *et al.*, 2012) [5]. The maximum value of stress is smaller than the ultimate yield strength of steel which shows designed value is suitable for fabrication. The von mises stress developed in chassis is as shown in Fig (7).

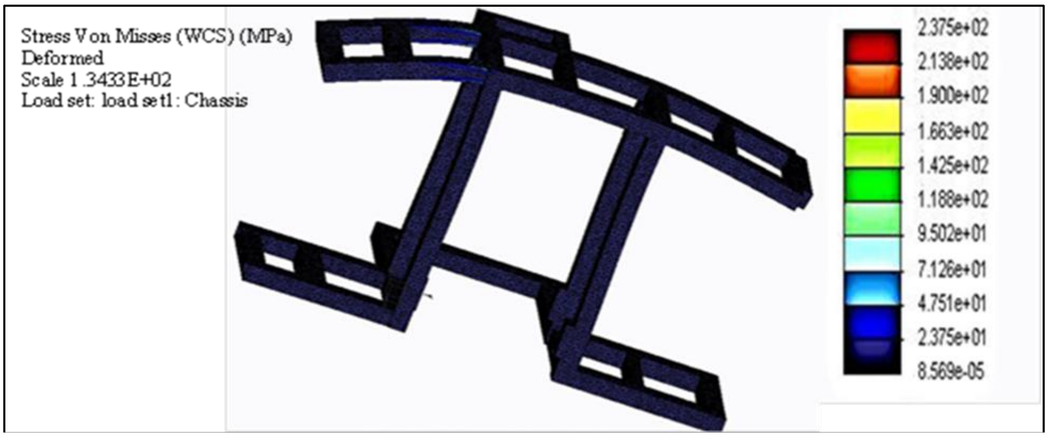

Fig. 7: Von Misses Stress developed on Chassis

3.2 Deformation analysis on Chassis

The maximum deformation occurs was 0.856 mm and it was occurs in top of chassis at the corner points (point 1 and point 2) as shown in Fig (8). It was because of high bending moment developed at the corners points due to normal load (Holden, J. T,. 1972).

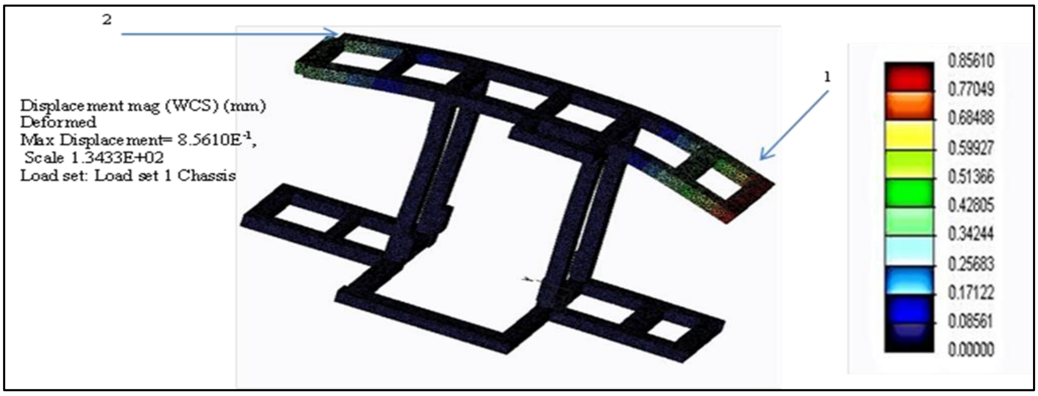

Fig. 8: Deformation produced on chassis after loading

Displacement curve was drawn for edge length between point1 and point 2 as shown in Fig (9). It shows that the deformation was more at corners than at the center points and minimum at the center points where reaction force is provided by rest of the system.

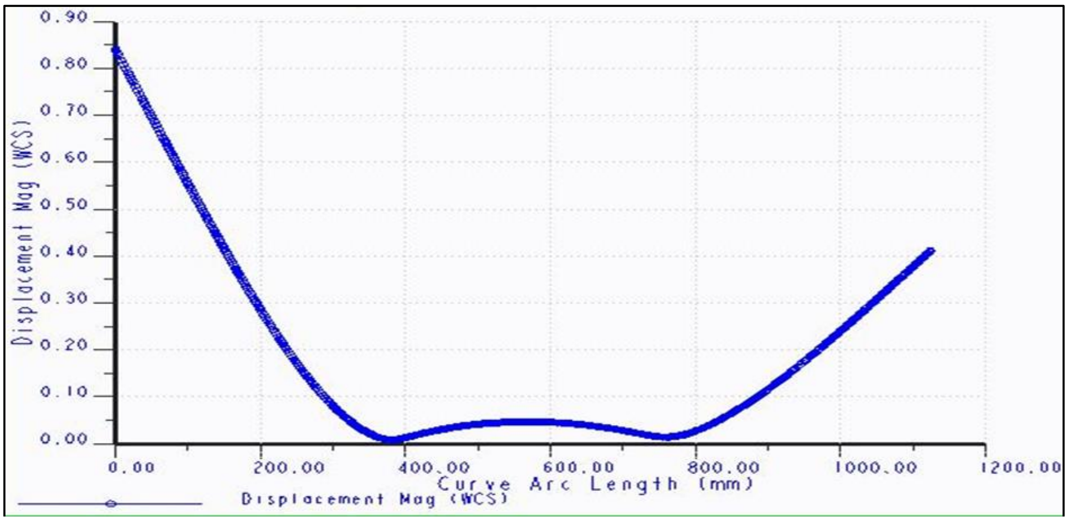

Fig 9: Deformation produced on chassis after loading from point 1 to point 2

3.3 Strain Analysis on Chassis: The maximum strain induced was observed to be 8.564×10^{-4} at the point of contact of welding is shown in Fig (10). It is due to the development of maximum stresses in these regions.

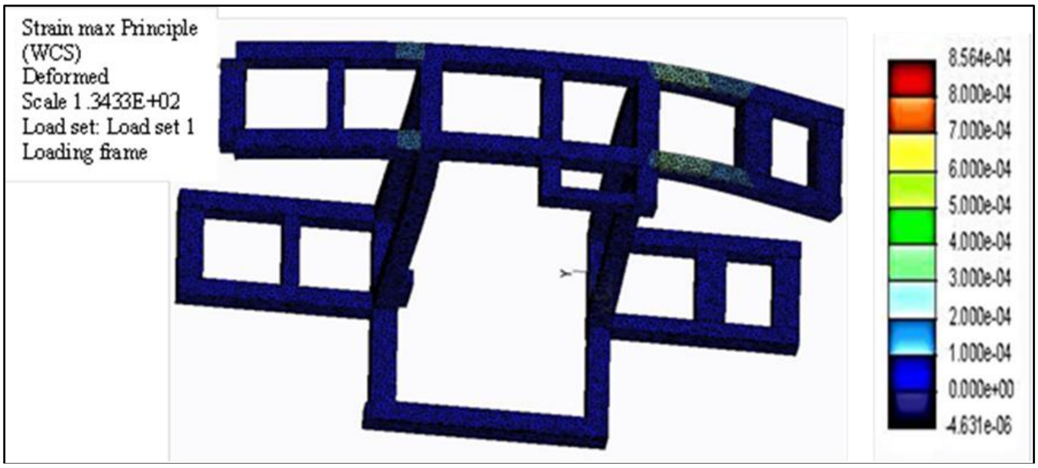

Fig. 10: Strain developed on chassis after loading

3.4 Power transmitting chain

Length of chain obtained from Equation 1, was 76 inch chain. Therefore it can be selected for final setup.

3.5 Drive shaft for power transmission

Since there was no bending moment on shaft, the shaft design was on basis of torque only. Diameter of shaft obtained was 50 mm (Factor of Safety (FOS= 1.8). Hence, a 50 mm mild steel shaft was fabricated at division workshop

4. Fabrication and assembly of test setup

The components of test setup were selected from the local market and fabricated at divisional workshop. The main frame of setup was fixed to base frame of existing soil-bin through nut bolts. The Chassis of test setup was attached to the main frame from three sides. Two were from the left and right sides of wheel with support from acrylic sheets subsystem and guide rails. The last mounting were from the front side of lab setup with support from the load cell. Inner space of chassis accommodates different tires. The tire took the load from chassis through shaft and bearing mounted on it. The top of chassis was provided with motor, motor controller and gear box. The power was transmitted from motor to top shaft via gearbox followed to the bottom driver shaft through chain and sprocket (Fig 1). For neutralizing the initial weight of test setup counter balancing unit was mounted over main frame. The developed single wheel setup could accommodate different sizes of the tires lesser than 70 cm diameter and up to 40 cm tire width. The selected tires were of sizes lesser than 70 cm tire diameter and 45 cm tire width. After selection and analyzing different components lab setup was assembled and fabricated (Fig 11).

Fig 11: Soil bin before (1) and after (2) mounting the lab test setup for testing tires

4.1 Characteristic of laboratory test setup

Advantages of this machine are that it comprised of fewer parts to provide wheel's power in comparison to other testing device. It can be best suited for analyzing the performance of smaller agricultural tires i.e. robotic tires and smaller tractor which could not be tested by bigger wheel testing device. The test setup was designed for maximum load (10kN) with maximum deformation of 0.856mm. The capacity of the load cell mounted is 3kN and the wheel angular velocity was adequate enough to provide sliding velocities up to 2.1 rad/s. The Lab setup has capability of self -Aligning the load cell with respect to hitch point of loading frame. It is provided with sufficient longitudinal space for changing tires. The largest tire diameter that will fit on the lab test setup is 70 cm and maximum width up-to 45 cm, tires greater than these dimensions could not be used. For changing the tires, test setup needs to be lifted by hitching additional weight manually to the counter balancing unit which requires 2 persons. It had no provision for changing the steering angle of wheel, wheel axis of rotation will always be in vertical direction. For effective utilization of soil bin length, the lab test setup needs to be lift up from soil bin and slides laterally to cover soil bin.

5. Conclusion

From the design and analysis of study, the following conclusions are drawn. The design is simple and compact with minimum fabrication cost. Chassis static analysis showed test setup was best up-to 10kN normal load. The maximum von mises stress, maximum deformation and maximum strain developed was 237.540Mpa, 0.856mm and 8.564×10^{-4} respectively. The largest tire overall diameter that will fit on the lab test setup is 70 cm and maximum width up-to 45 cm. This setup would provide a detailed idea about the tire-soil interaction. It could be helpful for obtaining best tire for a particular machine according to its size, load and operating condition.

6. Acknowledgment

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