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Automatic Adaptation of Tire Pressure According to Operating Conditions

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ABSTRACT:

The off-road vehicles have much higher rolling resistance due to tire sinkage. This paper presents a proposed system for automatic adaptation for tire inflation/deflation, according to operating conditions. The tire inflation pressure is manually changed by the driver to some prefixed pressure values. The proposed control system is based on calculating the instantaneous wheel slip ratio. As the slip ratio increases, the tire pressure decreases automatically to increase the contact area and to decrease the dynamic sinkage and vice versa. An algorithm for the control strategy is developed. The proposed system provides a continuous monitoring of tire pressures inside the tire and then to inflate/deflate according to terrain types. The results show that a low inflation pressure has a considerable effect on the net traction ratio where it improves the performance by 20% and the buffed tire has a better traction than lugged tire on sand.

KEYWORDS:

Terramechanics; Soil bin; Tire pressure; Inflation; Deflation; Slip ratio; Dynamic sinkage; Net traction ratio

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1. Introduction

Many features have been incorporated to increase the performance of off-road vehicles; but the tire remains the most important parameter. The traction performance for off road vehicles has been a challenging problem for many engineers. The soil-tire interface is responsible for about 20 to 55% of the losses of vehicle power, a factor that severely affects the amount of fuel used in drawbar implement applications [1]. In many studies, tire configurations and soil environments are investigated through experimental methods. The tests may be conducted either on soil bins or real field testing. The field testing may give the real conditions, but the uncontrolled environment may affect the results. In a soil bin, all driving conditions are controlled and used to acquire a significant amount of data [2]. Onwualu [3] developed and used the soil bin to study the basic soil mechanics. Reviewing the soil bins, about 36 different facilities in 12 countries had 90 soil bins constructed [4-5]. The soil bin facility consists of soil bin, tool carriage, drive system, instrumentation and data acquisition systems. The variations of cone index and soil compaction level are constant [6]. A proposed method to improve the vehicle performance is the adaptation of tire inflation pressure. On soft soil, reducing the tire inflation pressure causes the contact area to be larger and leads to a smaller sinkage [7]. Schlechter [8] studied the reduction of tire inflation pressure from 3.5 bars to 2 bars. The results showed a duplication of the traction force. Therefore most of military vehicles are equipped with central tire inflation systems (CTIS) to control the tire inflation pressure to improve the vehicle performance on different soils [9]. Some of CTIS is equipped with a digital control panel allowing the driver to change the inflation pressure according to the type of terrain. The designed pressure values for highway, cross-country, sand/mud and emergency are controlled.

Forrest et al [10] studied the effect of inflation pressure on vehicle performance. The results showed that as the inflation pressure decreased, the footprint of the tire became larger and distributed the load over a larger area. This leads to reduce the motion resistance in soft soils and helps to increase the transferable traction force, due to the enlargement of the tire tread area. Altunel and Hoop [11] studied the tire inflation pressure at 4.3 bars. The results showed a vehicle to travel only 65% of a selected terrain. Upadhyaya [12] studied the performance using the tire inflation pressure technique. The experimental results showed that as the tire inflation pressure decreases, the traction efficiency increases. Sünkel [13] compared the traction forces for two tires on sand. The results showed that, as the tire inflation pressure decrease from 550 to 110kPa, the traction force increases from 30kN to 100kN. The deflation time is about 70 seconds to decrease the tire pressure from 550kPa road-driving pressure to 110kPa self-freeing pressure [13].

This paper presents an automatic adjustment for tire inflation pressure without driver action. The tire pressure control circuit is based on the wheel slip ratio. Using the indoor soil bin facility testing, the instantaneous wheel slip ratio is calculated. As the slip ratio increases, the tire pressure decreases automatically until to the critical value (minimum pressure value given by manufacture to maintain the surface life of tires). This leads to increase in the contact area and thereby to decrease the dynamic sinkage. As the slip ratio decreases, the pressure inside the tire increases to the nominal value. Therefore the proposed system improves the vehicle performance.

2. Indoor soil bin testing

The indoor soil bin, as shown in Fig. 1, includes soil bin, moving carriage, towing trolley and tested tire [14]. The soil bin is designed from wood and reinforced with iron frame. Its overall dimensions are 6000×400×250 mm. It is provided with two metallic T-section side rails, mounted along the wood bin length. The side rails were used to facilitate movement of the towing carriage as well as soil processing trolley over the soil bin. This bin can be filled with different soils. In this work, a heavy duty off-road steel hub pneumatic off-road tire is used with a vertical load up to 136 kg at 207 kPa.

Fig. 1: Indoor soil bin facility test [14]

3. Tire pressure control circuit

The tire pressure control circuit is designed and assembled to enable inflating and deflating the tire. The main parts of a tire pressure control circuit include an air compressor with reservoir up to 10 bars maximum pressure, pressure regulator, directional control valve with double controlled solenoid, pressure sensor and rotary valve. The proposed control circuit has three states of operations, shown in Fig. 2. Jacob directional control valve has 5 ports and 3 changeable positions with two electrical solenoids for right/left positions and permanent signal spring to return to the middle position as shown in Fig. 3. The nominal voltage is 10 to 30 VDC, corresponding to the operating pressure range 2 bars to 20 bars. The instantaneous tire pressure is measured using pressure transducer (type PA-21G/25 Bar/81388.11). The input power supply is 10 to 24V DC and produces current from 4 to 20 mA according to the pressure change from 0 to 25 bars. So to convert this current to volt, a resistance of 980 Ohm is added as shown in Fig. 4. The output volt is 3.92 V to 19.6 V corresponding to current 4 to 20 m A. Rotary valve is used to deflate and inflate the tire during wheel rotation. It works as a mechanical conditioning system. It feeds pneumatic air from a stationary pipe to the rotating tire while rotation as shown in Fig. 5.

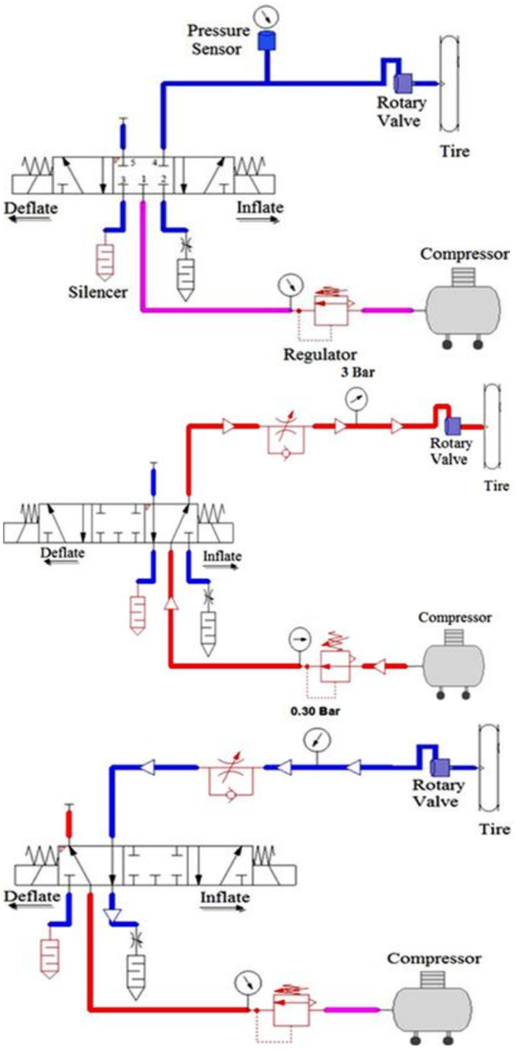

Fig. 2: States of tire pressure control - Normal position (top), Inflate position (middle) & Deflate position (bottom)

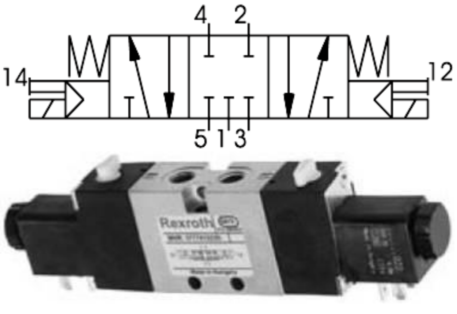

Fig. 3: Directional control valve

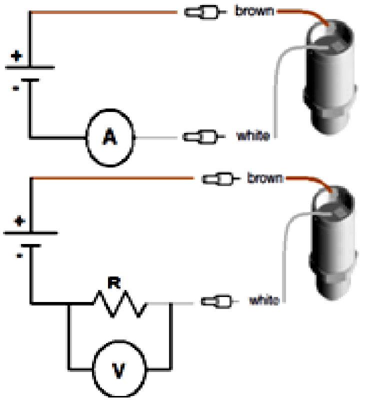

Fig. 4: Pressure sensor circuit

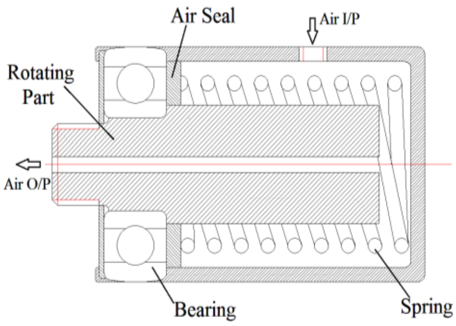

Fig. 5: Rotary valve

4. Development of control algorithm

The developed control system adjusts the inflation pressure between the operated maximum and minimum value according the tire specifications. The control algorithm for inflating/deflating is developed and implemented as shown in Fig. 6. The input parameters for control algorithm are the angular velocity of tire (ω_1), angular velocity of free wheel (ω_2) and initial inflation pressure (p_i). The operation of control algorithm is based on the slip ratio. The slip ratio is calculated by using two wheel speed sensors. The first one is attached with the wheel shaft, as shown in Fig. 7(a), to measure the theoretical speed (V_1) on soft surface. The other sensor is attached with free wheel on hard surface, as shown in Fig. 7(b), to measure the actual speed (V_2). The slip ratio is calculated as follows:

$$S = 100 \times (V_1 - V_2)/V_1 \qquad (1)$$

In terrain test, most of the vehicles are equipped with either traction control system or anti-lock braking system and these systems mainly depend on measuring the slip ratio. In the absence of these systems, a Peiseler wheel or Doppler radar sensor is required to measure the slip ratio. The system has three states of operations; inflate the tire at a low slip ratio ($S < 10$), deflate the tire at high slip ratio ($S \geq 20$) to the critical value) and hold the tire pressure between slip ratio, 10-20%. The control values are given in Table 1. The inflating or deflating time is variable and depends on the tire size.

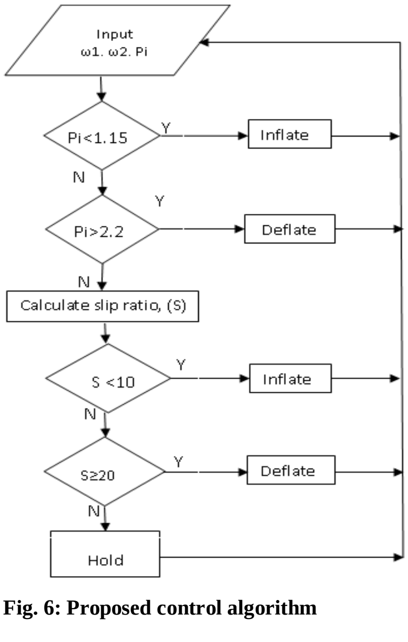

Fig. 6: Proposed control algorithm

Fig. 7(a): Measuring of theoretical speed

Fig. 7(b): Measuring of actual speed

Table 1: States of the control algorithm

State	Slip ratio, S %	Control
1	$10 < S < 20$	Pressure hold
2	$S < 10$	Pressure increase (inflate)
3	$S \geq 20$	Pressure decrease (deflate)

5. Experimental results & discussions

Using the indoor soil bin facility, the grain size distributions, soil density and soil strength are measured and the instantaneous slip ratio is calculated using two speed sensors. A sample of the experimental results is introduced. These include a monitoring of tire pressure inside the tire with time, measuring the vehicle performance in terms of net traction ratio and dynamic sinkage, in addition to the effect of multi-pass test. The grain size distribution is obtained experimentally for uniform fine sand and well graded soil by using Sieve analysis method as shown in Figs. 8(a) and (b) respectively. Uniform fine sand has a great effect on performance because it decreases the traction and increases the sinkage, especially in the third pass of multi-pass test due to the soil failure. The soil density is measured by using the sandy cone and sensitive balance. The sandy cone measures the volume of the sample while the sensitive balance measures the mass of the sample. The multi-pass test has a considerable effect on soil density due to compaction in soil layers. The dynamic sinkage is measured by using ultrasonic distance sensor. It has the advantages of the non-contact distance measurement module. So it is perfect for measuring distance between two moving or non-moving bodies. The ultrasonic sensor measures a range between 3cm to 4cm with input 5V DC power supply.

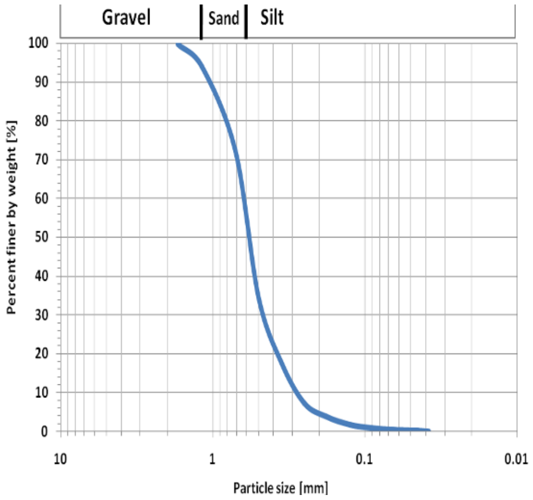

Fig. 8(a): Grain size distribution for uniform fine sand

Fig. 8(b): Grain size distribution for well graded soil

The dynamic shrinkage test is conducted to monitor the automatic variation of inflation pressure inside the tire according to the instantaneous slip ratio with time. Fig. 9 shows the variation of slip ratio, tire pressure and dynamic sinkage with time. As the slip ratio increases, the tire pressure decreases automatically up to the predetermined critical value (minimum pressure value given by manufacture) and leads to decrease the dynamic sinkage. In this test the critical value is 115 kPa. As the slip ratio decreases, the pressure inside the tire increases. Therefore, the proposed system improves the vehicle performance. There are three states of the variation of tire pressure with time; these are high pressure at start, low pressure at high slip ratio and high pressure at low slip ratio. Table 2 clarifies the variation of pressure values inside the tire at different states.

Table 2: Tire inflation pressure control states

State	Time [sec]		Inflation pressure [bar]	Slip ratio	Dynamic sinkage
	From	To			
1	0	8	Nominal tire pressure, 2.25	Increasing	Increasing
2	9	36	Decreased to minimum, 1.15	Decreasing	Decreasing
3	37	44	Increased to nominal, 2.25	Constant	Constant

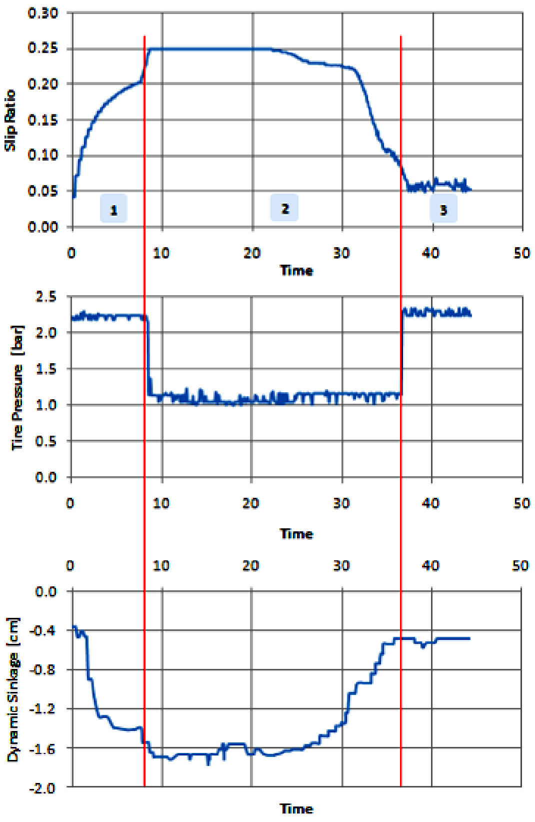

Fig. 9: Variations of tire slip ratio (top), tire pressure (middle) and dynamic sinkage (bottom) with time

The net traction (drawbar pull) is a force developed by the traction device. A loading mechanism is designed and implemented to measure the net traction, as shown in Fig. 10. Applying different vertical loads during tests to create a resistance force on the carriage motion, the drawbar pull and corresponding slip ratio are measured. This test is repeated with different vertical loads. The net traction ratio is the quotient of drawbar pull divided by the tire load as follows:

$$\text{Net traction ratio} = \frac{\text{Drawbar pull}}{\text{Tire load}} = \frac{DP}{W} \tag{2}$$

The vehicle performance has been investigated in terms of the net traction ratio at high and low tire inflation pressures (225kPa and 115kPa respectively) on loose soil with characteristics as shown in Fig. 8. The variations of net traction ratios with the slip ratio at high and low inflation pressure are shown in Figs. 11(a) and (b). The low inflation pressure has a considerable effect on the net traction ratio where it improves the performance by 20%.

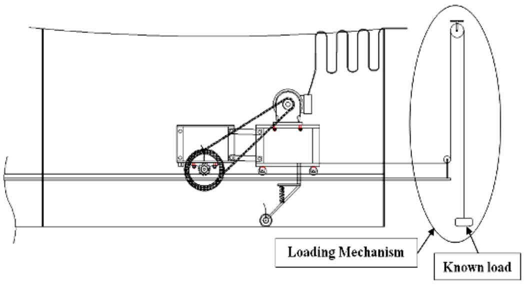

Fig. 10: Tension loading mechanism

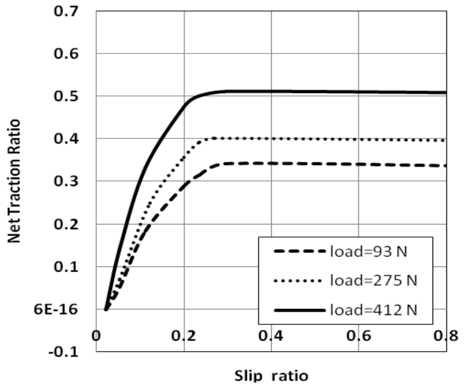

Fig. 11(a): Variations of net traction ratio with slip ratio at high pressure

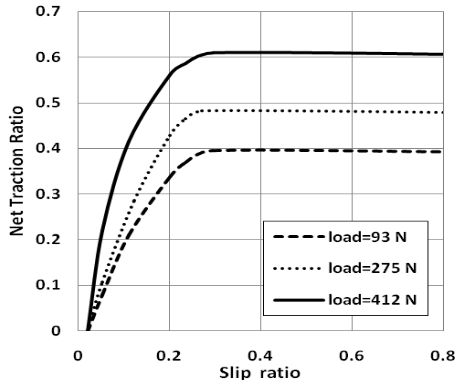

Fig. 11(b): Variations of net traction ratio with slip ratio at low pressure

The multi-pass test has an influence on the terrain properties. The impact of tire on soil depends on the number of passes. The multi-pass test is done for lugged and buffed tires. The experimental results of test are recorded for (1st, 3rd, 6th and 9th) passes. The effects of these passes are calculated by the maximum net traction ratio and the soil density change. Fig. 12 shows the variation of net traction ratio in multi-pass test for lugged and buffed tires. The buffed tire has a better traction than lugged tire on sand and has a considerable effect about 5% than lugged tire. The variation of soil density with number of passes is shown in Fig. 13. As the number of pass increases, the soil density increases.

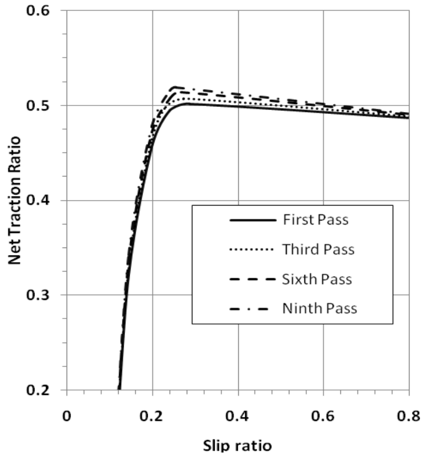

Fig. 12(a): Variations of net traction ratio with slip ratio in multi-pass test - Lugged tire

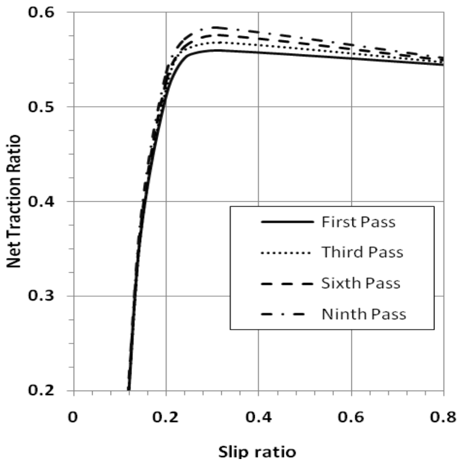

Fig. 12(b): Variations of net traction ratio with slip ratio in multi-pass test - Buffed tire

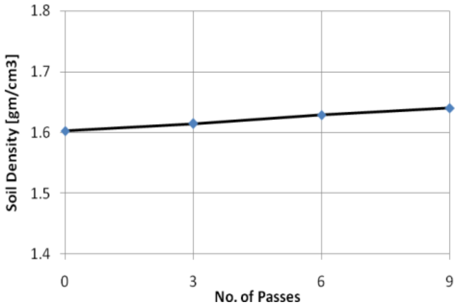

Fig. 13: Variations of soil density with number of passes

6. Conclusions

A proposed system for automatic adaptation for tire inflation/deflation according to operating conditions is introduced. The new proposed control system is based on calculating the instantaneous wheel slip ratio. As the slip ratio increases, the tire pressure decreases automatically up to the predetermined critical value set by the manufactures. This leads to increase in the contact area and decrease in the dynamic sinkage and vice versa. As the slip ratio decreases, the pressure inside the tire increases to the nominal value. The required control algorithm for the control strategy is developed and implemented. The system provides a continuous monitoring of tire pressure inside the tire and inflates/deflates according to terrain type. The proposed system has three states of operation with time according to the instantaneous slip ratio. These are high pressure at small slip ratio, low pressure at high slip ratio and hold the pressure between certain values of slip ratio. The time histories of all measuring sensors - speed, slip ratio, dynamic sinkage and tire pressure are recorded and processed. The vehicle performances in terms of the net traction ratio and dynamic sinkage are investigated on uniform fine sand and well graded soil. The results show that a low inflation pressure has a considerable effect on the net traction ratio where it improves the performance by 20%. The buffed tire has a better traction, about 5%, than lugged tire on sand.

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REFERENCES:

[1] F. Zoz and R.D. Grisso. 2003. Traction and tractor performance, *Proc. Agricultural Equipment Tech. Conf.*, Louisville, USA.

[2] S.K. Upadhyaya, J. Mehkschau, D. Wulfson and J.L. Glancey. 1986. Development of a unique mobile single wheel testing device, *Trans. ASAE*, 29(5), 1243-1246. http://dx.doi.org/10.13031/2013.30303.

[3] A.P. Onwualu and K.C. Watts. 1989. Development of a soil bin test facility, *ASAE*, Paper No. 89-1106, St. Joseph, MI.

[4] R.D. Wismer and H.J. Luth. 1974. Off-road traction prediction for wheeled vehicles, *Trans. ASAE*, 17(1), 8-14. http://dx.doi.org/10.13031/2013.36772.

[5] R.K. Wood and L.G. Wells. 1983. A soil bins to study compaction, *ASAE*, Paper No. 83-1044, St. Joseph, MI.

[6] M. Naderi-Boldaji, R. Alimardani, A. Sharifi and A. Tabatabaeefar. 2009. Economical hand-pushed digital cone penetrometer, *Int. Agrophysics*, 23, 55-60.

[7] T.F. Czako. 1974. The Influence of the inflation pressure on cross-country performance, *J. Terramechanics*, 11(3-4), 13-23. http://dx.doi.org/10.1016/0022-4898(74)90020-2.

[8] H.P. Schlechter. 1994. Design and performance of central tire inflation systems, *Proc. 6th European ISTVS Conf.*, Austria.

[9] G.H. Hohl. 2007. Military terrain vehicles, *J. Terramechanics*, 44, 23-34. http://dx.doi.org/10.1016/j.jterra.2006.01.003.

[10] P.J. Forrest, I.F. Reed and G.V. Constantakis. 1962. Tractive characteristics of radial-ply tires, *Trans. ASAE*, 43(11), 108-115. http://dx.doi.org/10.13031/2013.40948.

[11] A.O. Altunel and C.F. Hoop. 1998. The effect of lowered tire pressure on a log truck driver seat, *Int. J. Forest Engg.*, 9 (2), 41-47.

[12] S.K. Upadhyaya and D. Wulfsohn. 1990. Traction prediction for radial ply tires, *Proc. 10th Int. ISTVS Conf.*, Kobe, Japan.

[13] W. Sünkel. 1994. Influence of advanced chassis technology on off-road mobility determined by means of the 8x8 experimental vehicle, *Proc. 6th European ISTVS Conf.*, Austria.

[14] A. Hendy, S. Hegazy, M.A. Emam and Y. Hendawy. 2013. Development of an in-door soil bin testing facility experimental setup, *Proc. 15th Int. Conf. Aerospace Sciences & Aviation Tech.*, Cairo, Egypt.