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A ¼ SCALE HYBRID FULL-TRACKED AIR-CUSHION VEHICLE FOR SWAMP PEAT TERRAIN IN MALAYSIA

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ABSTRACT

This paper describes design and development of a hybrid full rubber track air-cushion vehicle (HTACV) for collection-transportation operation of palm oil fresh fruit bunches (FFB) on the low bearing capacity of 7 kN/m^2 swamp peat terrain. The full segmented rubber track mechanism is used as the driving system to overcome the rolling motion resistance and the air cushion system is used to increase the floatation capacity of the vehicle. The driving force is provided to each of the track system by an individual AC motor. The additional thrust (or ,tractive effort) is provided to the vehicle by using two propulsion systems for overcoming the drag resistance of the air-cushion system. Mathematical models are incorporated by accounting the kinematics and dynamics behavior of the vehicle. The simulation of the tractive performance has been found as 65% traction coefficient and 80% tractive efficiency.

Keywords: HTACV, Peat terrain, Bearing capacity, Tractive performance.

1. INTRODUCTION

Collection and transportation operation of oil palm fresh fruit bunches (FFB) on swamp peat terrain in Malaysia particularly in Sarwak and Sabah are greatly emphasized to design and develop the vehicles with high crossing ability, good tractive performance and maneuver on swamp peat terrain. Many research works have been carried out and different types of prototypes have been introduced Bekker (1969), Wong *et al.,* (1982), Wong (2001), and Ataur *et al.,* (2005) for the collection and transportation operations of oil palm FFB in Malaysia on soft terrain including peat terrain. However, most of the vehicles were wheeled vehicles, tracked vehicles and hybrid air-cushion vehicles including fully track and fully tyre-wheeled air-cushion vehicles. It is found that the air-cushion system of all the existing vehicles are fixed in such a way that it always slides with the movement of the vehicle which may result excessive power consumption. Therefore, the air-cushion system should be fixed just few millimeters top of the ground that it could be used when it is needed. In adding that since the vehicle is supported by both tracked system and air-cushion, the contact area of the tracked system and air-cushion must be determined properly in order to optimize the power utilization.

A hybrid vehicle which combines air-cushion technology with a driving mechanism has been proven to be an efficient solution for a heavy duty vehicle on severe working conditions (Luo et. al., 2003). This study proposed a hybrid fully segmented rubber tracked air-cushion vehicle which would provide the solution of collection and transportation operation of palm oil on low bearing. capacity (7 kN/m^2) swamp peat terrain.

2. DESCRIPTION OF PROPOSED VEHICLE

The proposed vehicle will be comprised mainly with full track system, skirt air-cushion and air-cushion propulsion system, AC motors, two propellers, a battery pack, and a small engine are shown in figure 1. The full segmented rubber track mechanism will be used as driving system to overcome traveling resistance, and the flexible skirt air-cushion as vehicle body to support vehicle partial weight. The driving force will be provided to each of the track system by an individual AC motor. The skirt air-cushion system will be mounted with the inner sides of the tracked system and just 50mm from the bottom of the tracked system. The additional thrust will be provided to the air-cushion system by two small propellers. The vehicle could run on the unprepared swamp peat terrain at least 100 km from a single charging battery. After traveling the vehicle 90km the battery will be recharged by the engine automatically. The automatic recharging system of the battery will be incorporated by introducing a Hall Effect Sensor. The air-cushion system will be used to make the vehicle ground contact pressure even less than 5kN/m^2. The hovering pressure to the air-cushion will be provided by a single compressor to support the partial vehicle weight.

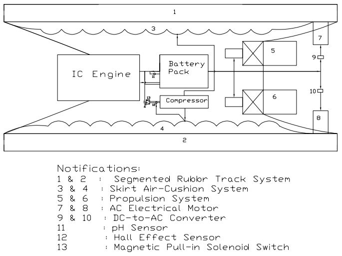
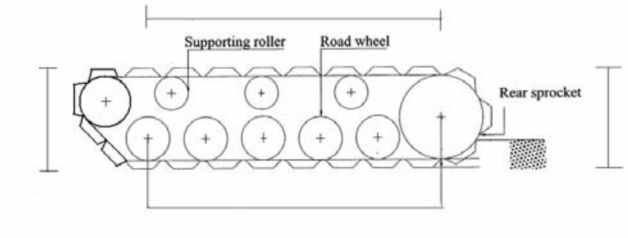


Fig 1: 2D Structural view of the vehicle

The compressor will start automatically when any of the tracks sink 50mm. The starting system of the compressor will be incorporated by using an inductive sensor. The AC motors, the compressor, and the propeller will receive power from a rechargeable high amp-hr battery. Small IC engine will be used to recharge the battery if the vehicle operate more that 90 km. Figure 2 shows the track system of the vehicle.



Notifications: S1= Section 1, S2=Section 2, S3=Section 3, S4=Section

Fig 2: Track system

3. MATHEMATICAL MODEL

Basically, there are two types of mathematical modeling one of them considers the uniform ground pressure distribution and another one involved non-uniform ground pressure distribution. This sudy presents the mathematical modelling for the uniform ground pressure distribution (UGPD) shown in Figure 3.

A tracked vehicle develops its tractive effort by deforming the soil in longitudinal shear. As the vehicle moves across the soil, a counter force arises from the soil and is equal to the tractive effort. In other sense, it can be defined as the force of the vehicle that can be generated at the terrain interface. The tractive effort is developed not only at the ground contact part of the track but also at the track sides. However, for this project we are considering only the tractive effort developed at the bottom part of the track. To add, the tractive effort of the vehicle in this study is going to be calculated in two ways.

(i) For sinkage, $0 \le z \le 5cm$

The tractive effort of the vehicle can be represented as the shearing stress effect of the vehicle track system. Therefore, the tractive system of the vehicle can be represented as follows:

$$F = 2B\int_0^L \tau dx \tag{1}$$

The τ is the shear stress of the terrain in kN/m^2 which can be found by using the following equation provided by Wong (2001).

$$\tau = \tau_{\max}\left(\frac{j_x}{K_w}\right)\exp\left(1-\frac{j_x}{K_w}\right)$$

Where, $\tau_{\max} = (c + \sigma\tan\varphi)$ and $j_x = ix$

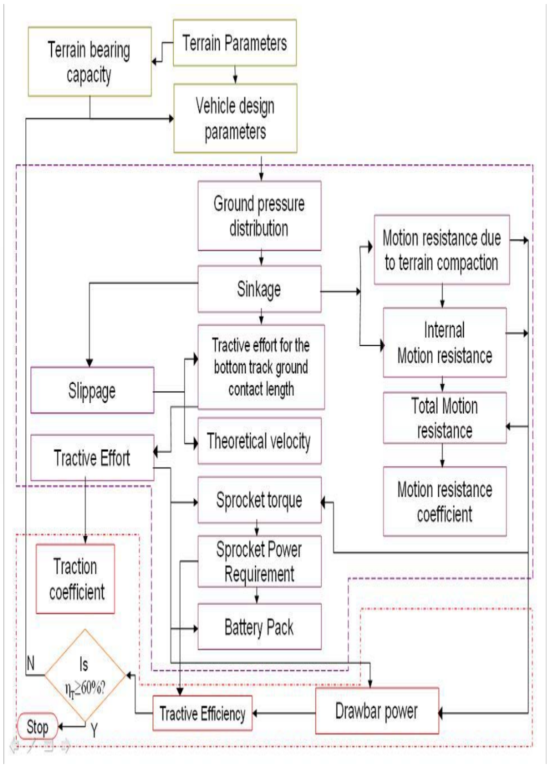


Fig 3: Flow chart for the model of vehicle straight motion with UGPD

By integrating the Eq. (1), the tractive effort equation for the bottom of the vehicle's track ground contact part on peat terrain was derived by the Ataur et.al (2005):

$$F_b = \left(A_t c + (W + W_c)\tan\varphi\right)\left[\frac{K_w}{iL}e^1 - \left(1+\frac{K_w}{iL}\right)\exp\left(1-\frac{iL}{K_w}\right)\right] \tag{2}$$

where, F_b is tractive effort that develop at the bottom part of the track in kN and L is the ground contact part of the track in m, A_t is the area of the track ground contact length in m^2, σ is the vehicle normal stress kN/m^2, W is the total load of the vehicle in kN, W_c is the air cushion load, c is the cohesiveness in kN/m^2, φ is the terrain internal friction angle in degree, K_w shear deformation modulus in m, i is the slippage of the vehicle in percentage.

(ii) For sinkage, $z \geq 5cm$

The tractive effort of the vehicle is calculated by using the equation of Luo et al. (2003) as cited in Ataur et. al (2005) :

$$F_{tc} = \left(A_t c + W \tan\varphi\right)\left[\frac{K_w}{iL}e^1 - \left(1+\frac{K_w}{iL}\right)\exp\left(1-\frac{iL}{K_w}\right)\right] + C_{sk}P_cA_c \tag{3}$$

where, F_{tc} is the tractive effort of the vehicle after the air-cushion touches the terrain in kN, P_c is the air pressure in cushion in kN/m^2, and A_c is the cushion effective area in m^2.

3.1 Motion Resistance

The motion resistances from aerodynamics and track belly drag component in the computations of the total motion resistance are not significant. Hence, the total motion resistance due to track compaction will affect the vehicle differently for different values of sinkage.

(i) For sinkage, $0 \leq z \leq 5cm$

$$R_t = R_c + R_{in} \tag{4}$$

(ii) For sinkage, $z \geq 5cm$

$$R_t = R_c + R_{in} + R_{sk} \tag{5}$$

where, R_c is the motion resistance of the vehicle due to terrain compaction in kN, R_{in} is the vehicle rolling components internal frictional resistance, and R_{sk} is the skirt-ground interaction resistance in kN.

The motion resistance of the vehicle due to terrain compaction can be represented by the simplified equation of Wong, J. Y. (2001) given first in general formulation:

$$R_c L = 2BL\int_0^z p\,dz \tag{6}$$

where, p is the ground contact pressure. It can be calculated by using the equation provided by Wong , J. Y. (2001):

$$p = (k_p z + \frac{4}{D_h} m_m z^2)$$

By integrating the Eq. (6), the motion resistance equation was derived by Wong, J. Y. (2001) :

$$R_c = 2B\left(\frac{k_p z^2}{2} + \frac{4}{3D_h} m_m z^3\right) \tag{7}$$

where, R_c is the vehicle motion resistance due to soil compaction in kN.

(i) For sinkage, $0 \leq z \leq 5cm$

$$R_c = 2B\left(\frac{k_p z_1^2}{2} + \frac{4}{3D_h} m_m z_1^3\right)$$

(ii) For sinkage, $z \geq 5cm$

$$R = 2B\left(\frac{k_p z_2^2}{2} + \frac{4}{3D_h} m_m z_2^3\right) + C_{sk}P_cA_c$$

3.2 STUDIES ON DESIGN PARAMETERS

Vehicle design parameters has been studied by considering the Sarwak peat terrain's lowest bearing capacity and the lowest sinkage and the lowest value of mechanical parameters as shown in Table 1.

Table 1: Terrain parameters (Ataur *et al*. (2004))

Parameters	Un-drained	
	Sepang Mean value	**Sarwak** Mean value
ω, (%)	90.51	98
γ, (g/cm^3)	0.082	0.045
c, kN/m^2)	0.78	0.38
φ, (degree)	12.64	20
K_w, (cm)	0.635	1.24
m_m,(kN/m^3)	14.42	7.42
k_p, (kN/m^3)	119.65	59.65

There are three types of loaded vehicle such as 3.92 kN, 5.88kN and 7.82 kN and the vehicle traveling speed 10 km/h are considered for the study of the vehicle design parameters.

Figure 4 shows one of a moderate condition peat terrain in Malaysia. From the observation, the water table was found very high and the terrain surface mat thickness was found in the range of 0-5 cm and 0-12 cm. The bearing capacity of the Sarwak peat terrain 7kN/m² and surface mat thickness 5cm are considered. The simulation on the vehicle parameters are conducted by using the MATLAB, RECRDYNE and Microsoft Excel.

(a) before drainage (b) after drainage

Fig 4: Photograph of the moderate peat terrain

Figure 5 shows the vehicle sinkage for three different loading conditions. In this study the track ground contact length is kept constant at 1.00 m and tracked width 0.254 m which is available in the market as needed. Therefore, the vehicle track ground contact area is always considered as 0.508 m^2. From the Figure 5, it is observed that the vehicle sinkage is found more than 5.0 cm for all of the vehicle's loading conditions. As the terrain mechanical parameters such as k_p,and m_m,and track size L and B are constants, so it is important to increase the vehicle ground contact area in order to get the vehicle sinkage 5 cm and ground contact pressure 7 kN/m^2.

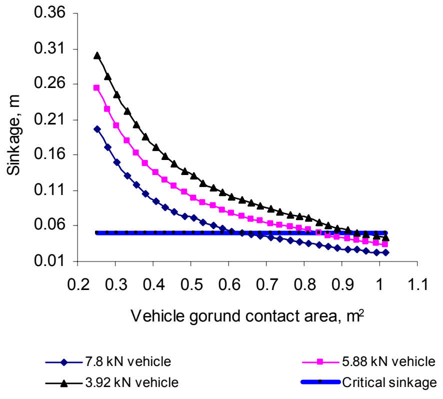
The ground contact pressure of the vehicle with air cushion system is less compared to an identical vehicle without an air cushion. This is due to the fact that when the air cushion is taken into consideration, the corresponding hydraulic diameter is increased. Moreover, the air cushion is used to support partial load of the vehicle, causing the ground contact pressure to decrease as the sinkage is increased.

Furthermore, the air cushion increases the ground contact area of the vehicle and results decrease the ground contact pressure and increase mobility of the vehicle over the unprepared peat terrain. Ground contact area only for the vehicle's track is considered 0.508 m^2. With this track ground contact area, the vehicle will able to traverse on the Sarwak peat terrain with any loading condition as the sinkage is higher than 5 cm. It can be noted that motion resistance due to compaction increases as the track width increases from 0.127 m to 0.381 m by considering k_p, m_m, L and W are constants, having the values of 119.65 kN/m^3, 14.42 kN/m^3, 1m and 5.886kN respectively. But, if the vehicle equipped with air-cushion system of ground contact area 0.544 m^2, the vehicle will able to traverse on the Sarwak swamp peat terrain with all of the loading conditions.

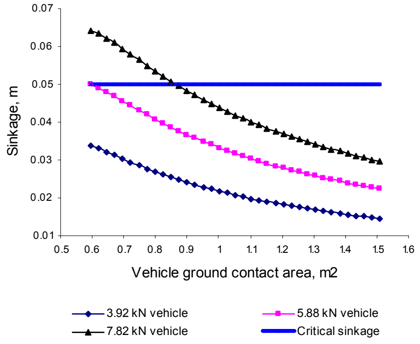
In order to evaluate the performance of the vehicle on the peat-terrain, the behavior of the ground contact pressure with respect to sinkage is illustrated in Figure 6. In the early of this study, it is mentioned that the critical ground contact pressure of the vehicle on Sarwak peat terrain is 7kN/m^2.

Figure 6 (a) shows that the vehicle could be allow to traverse on the Sarwak swamp peat terrain with all three loading conditions only if the vehicle is equipped with ground contact area 1 m^2 or more (i.e, $1.00 \le A_t$) but the track ground contact area is only considered 0.508 m^2. Figure 5 (b) shows that if the vehicle which track ground contact area of 0.508 m^2 is equipped with 0.544 m^2 air-cushion, vehicle would traverse on the swamp peat terrain easily.

Figure 7 shows the relationship between the vehicle tractive effort and motion resistance. Figure 7 (a) shows that if the vehicle terrain compaction motions within the shaded area or the tractive effort the vehicle is only able to traverse on the peat terrain. Moreover, the vehicle total contact area is used 1.052 m^2 including 0.544 m^{2}of air-cushion area. The vehicle has needed to develop additional 0.5 kN tractive effort in order to traverse on the peat terrain with overcoming only the compaction motion resistance. Again, Figure 7 (b) shows that for the vehicle ground contact area of 1.052 m^2 including 0.544 m^2 of air-cushion area vehicle has needed to develop additional 0.75 kN. Therefore, this study represented propeller system, which will able to develop 1.0kN tractive effort to traverse the vehicle on swamp peat terrain.

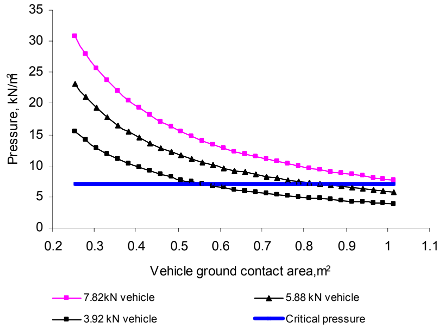


(a)

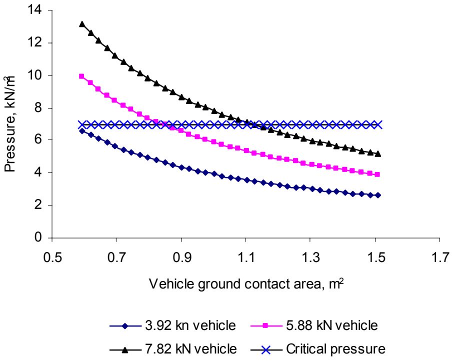


(b)

Fig 5: Vehicle sinkage (a) without track system, (b) with track system.

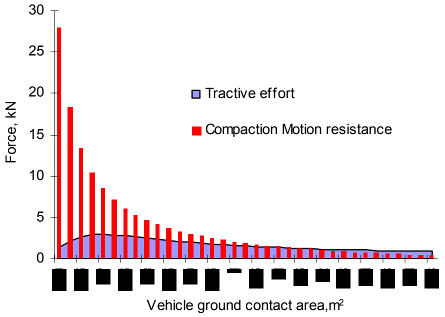


(a)

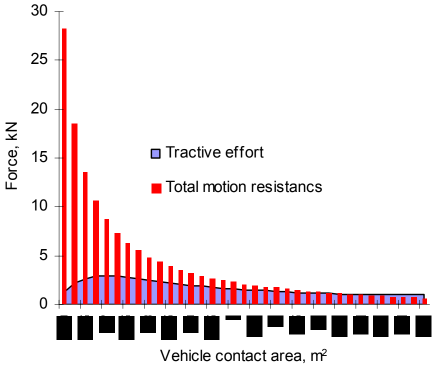


(b)

Fig 6: Vehicle ground contact pressure (a) without air-cushion (b) with air-cushion



(a) Compaction motion resistance



(b) Total motion resistance

Fig 7: Tractive effort and motion resistance

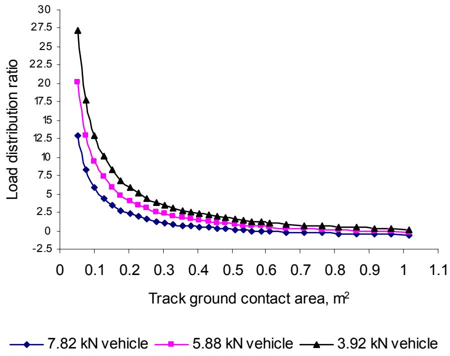


Fig8: Load distribution

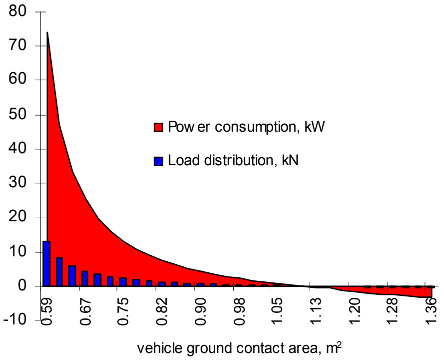


Fig 9: Power consumption

Figure 8 shows the load distribution (define as the load transferred from the traveling system to air-cushion system in order to limit the vehicle sinkage and to maintain the vehicle ground contact pressure distribution). The load distribution to the air-cushion system is decreased linearly with increasing the track ground contact area. It is noted that the required driving force increases with decreasing the load distribution. Figure 9 shows the load distribution to the air-cushion significantly affect the total power consumption of the vehicle.

4. CONCLUSIONS

A new design method with propeller is proposed for a ¼ scale hybrid full rubber track air cushion vehicle (HTACV) for collection-transportation operation of palm oil fresh fruit bunches (FFB) on the low bearing capacity of 7 kN/m^2 swamp peat terrain and a prototype of the vehicle is developed. The driving force is provided to each of the track system by an individual AC motor and two propulsion systems are used for overcoming the drag resistance of the air-cushion system.

(i) Based on the simulation results, the following conclusions could be made:

- Vehicle ground pressure could be made 7 kN/m^2 by adding 0.544 m^2 air-cushion with track ground contact area of 0.508 m^2.
- Tractive performance has been found as 65% traction coefficient and 80% tractive efficiency.
- Optimal load distribution ratio results in minimum total power consumption.

(ii) The vehicle could be made suitable for operating on the swamp peat terrain with optimizing the supporting systems as 0.544 m^2 air-cushion and track ground contact area of 0.508 m^2.

5. ACKNOWLEDGEMENT

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7. NOMENCLATURE

Symbol	Meaning	Unit
z	Sinkage	(cm)
F	Tractive effort	(kN)
τ	Shear stress	(kN/m^2)
F_b	Tractive effort at the bottom	(kN)
L	Track ground contact length	(m)
A_t	Track ground contact area	(m^2)
σ	Vehicle normal stress	(kN/m^2)
W	Total load of the vehicle	(kN)
W_c	Air cushion load	(kN)
c	Cohesiveness	(kN/m^2)
φ	Terrain internal friction angle	degree
K_w	Shear deformation modulus	(m)
i	Slippage of the vehicle	(%)
F_{tc}	Tractive effort of vehicle after the air-cushion touches terrain	(kN)
P_c	Air pressure in cushion	(kN/m^2)
A_c	Cushion effective area	(m^2)
R_c	Motion resistance of vehicle due to terrain compaction	(kN)
R_{in}	vehicle rolling components internal frictional resistance	(kN)
R_{sk}	Skirt-ground interaction resistance	(kN)
D_h	Hydraulic diameter	(m)
P	Ground contact pressure	(kN/m^2)