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Research Article
Effect of Sinkage on the Tracked Vehicle Performance with an Intelligent Additional Track Mechansim for Swamp Peat Vehicle

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Abstract
Background and Objective: In order to find a better vehicle that can maneuver on swamp peat terrain with 7 kN m^{-2} bearing capacity, various designs of tracked vehicle have been produced but none of them could operate effectively over swamp peat terrain. In order to overcome the limitation of the movement of tracked vehicle over swamp peat terrain a tracked vehicle with an additional track mechanism has been designed. This study presents the vehicle performance (in terms of motion resistance and power consumption) in swamp peat with additional track system and compares the performance with other existing tracked vehicle. **Methodology:** By using developed mathematical model for the vehicle, the value of the vehicle sinkage is used as the input for the vehicle motion resistance and power consumption. The range of the vehicle sinkage is varied from 0.0061 m until 0.0444 m with the maximum limit of 0.070 m. **Results:** From the results, it is found that the sinkage of tracked vehicle with additional track mechanism is less than the tracked vehicle without an additional track. While, the motion resistance and power consumption are increased with increasing of vehicle sinkage. **Conclusion:** Hence, the sinkage of the tracked vehicle in swamp peat does affect the performance of the vehicle.

Key words: Swamp peat vehicle, additional track, vehicle sinkage, motion resistance, power consumption, tracked vehicle

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Mobility issues on swamp peat terrain have been discussed since years back as the exploration on swamp peat keep increasing[1]. The bearing capacity of the swamp peat terrain which is very low of about 7 kN m^{-2} make people in automotive industries facing difficulties as they need to make sure the vehicle did not sink in the swamp peat during the operation[2]. Various designs of swamp peat vehicle such as intelligent air-cushion tracked vehicle and segmented rubber tracked vehicle have been developed to solve the problem[3,4]. However, a vehicle that can maneuver swamp peat terrain effectively has not yet been found. Hence, tracked vehicle with an additional track mechanism would be developed and further study on the performance of that vehicle need to be done.

The additional track mechanism is implemented in the middle frame of the tracked vehicle to support the tracked vehicle from being sunk in swamp peat during the operation. Furthermore, the additional track mechanism is designed so that it can be folded in normal condition and unfolded when the vehicle experiences the sinkage. Based on the previous study, the vehicle sinkage in swamp peat provided significant influence towards the tracked vehicle performance[5]. In this study, the effects of vehicle sinkage on the vehicle performance in term of motion resistance and power consumption would be investigated. The mathematical model for the vehicle performance has been developed to carry out the analysis. The entire mathematical model is developed based on the previous study.

MATERIALS AND METHODS

Tracked vehicle structure: A prototype of tracked vehicle with an additional track mechanism is illustrated in Fig. 1. The design of the additional track mechanism is smaller than the main track so that it can be fitted in between the two main tracks and the middle frame of the tracked vehicle. Ball-screw lift mechanism is attached to the additional track for the movement purpose upwards and downwards. Two motors are mounted to the main tracks sprocket as the driving force and one motor is used to drive the ball-screw lift mechanism. The additional track mechanism is used to support the tracked vehicle from being sunk in the swamp peat during the operation where, it can be folded on the normal surface area and unfolded when the tracked vehicle experiences the sinkage. The details of the tracked vehicle with an additional track mechanism has been discussed in previous research articles[6,7]. In order to optimize the design of the tracked vehicle with an additional track mechanism, further study on the vehicle performance is needed.

Vehicle sinkage: In obtaining the traction performance of the tracked vehicle, vehicle sinkage is the important part to be studied. It is reported that, the sinkage of the tracked vehicle cannot exceed 70 mm in the swamp peat in order to survive on it[3]. Equation 1 present the formulated vehicle sinkage based on the vehicle and terrain condition:

$$z_2 = \frac{-\left(\frac{k_p D_{hta}}{4m_m}\right) \pm \sqrt{\left[\left(\frac{k_p D_{hta}}{4m_m}\right)^2 + \frac{D_{hta}}{m_m} p_{gta}\right]}}{2} \quad (1)$$

with:

$$D_{hta} = \frac{4L_{ta}B}{2(L_{ta}+B)}$$

$$L_{ta} = (L_{XY}\cos\theta + L + R_{rs}\sin\theta),\ L_{XY} = \frac{z}{\sin\theta},\ p_{gta} = \frac{W_{ta}}{A_{ta}}$$

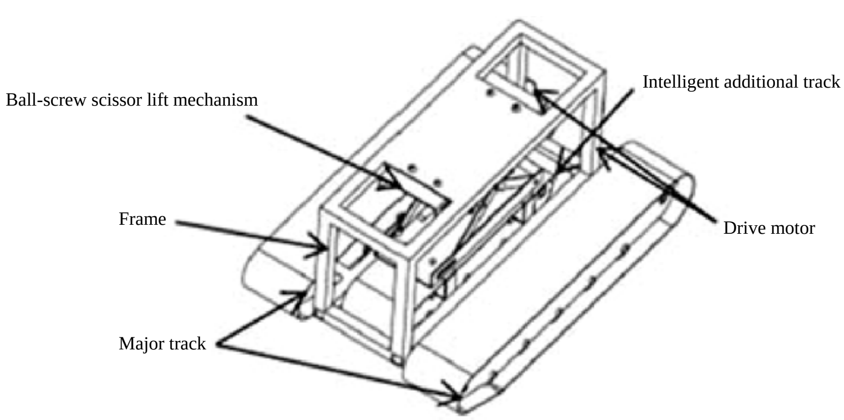

Fig. 1: Additional track mechanism structure

Where:

$$A_{ta} = 2\,(L_{ta} \times B),\;\; W_{ta} = W_t - W_{v(ad)} = (1-\delta)W_t \text{ and } \delta = \frac{W_a}{W_t}$$

where, D_{hta} is the track hydraulic diameter when additional track touches the ground in m, L_{ta} is the trackground contact length when additional track touches the ground in m, A_{ta} the ground contact area when additional track touches the ground in m^2, W_{ta} is the vehicle load supported by the track system in kN, $W_{v(ad)}$ is the vehicle partial load supported by the additional track mechanism in kN, δ is the load distribution ratio, R_{rs} is the radius of the rear sprocket in m, θ is the angle between track of the first road-wheel to tensioned wheel and to the ground degrees and p_{gta} is the vehicle ground contact pressure when the additional track touches the ground.

Theoretical model of motion resistance: As the tracked vehicle is moved only within 10-15 km h^{-1}, the motion resistance of the tracked vehicle with an additional track mechanism is ignored while the motion resistance is measured based on the soil compaction and internal friction of moving mechanism:

$$R_{ta} = R_c + R_{in} + R_{in(add)} = 2B\left(\frac{k_p z^2}{2} + \frac{4}{3D_{hta}} m_m z^3\right) + \left(\frac{W_{ta}}{1000\,g}\right)(222+3v) + \left(\frac{W_{ta}}{1000\,g}\right)(222+3v) \quad (2)$$

where, in Eq. 2, R_{ta} is the total motion resistance of the vehicle when the additional track touches the ground in kN, R_c is the terrain compaction motion resistance in kN, R_{in} is the motion resistance due to the internal friction of the moving parts in kN, $R_{in(add)}$ is the internal friction of the moving part in additional track mechanism in kN, W_{ta} is the load supported by the track system in kN, g is the gravitational acceleration in m sec^{-2} and is the vehicle velocity in m sec^{-1}.

Total power consumption: Power consumption is the electrical energy required to operate a vehicle. The vehicle sinkage is found to significantly affect the amount of power needed to move the tracked vehicle[8]. Equation 3 expressed the power consumption mathematical model as below:

$$P_{ta} = R_{ta} v_t = (R_c + R_{in} + R_{in(add)})\, v_t \quad (3)$$

where, P_{ta} is the total power consumption of the tracked vehicle with an additional track mechanism in kW, R_{ta} is the total motion resistance when additional track touches the ground in kN, R_c is the motion resistance due to the terrain compaction in kN, R_{in} is the terrain internal friction due to the moving parts in kN, $R_{in(add)}$ is the internal friction of additional track moving part and is the vehicle velocity in m sec^{-1}.

RESULTS AND DISCUSSION

The performance of the tracked vehicle which are motion resistance, traction force and power consumption of the tracked vehicle could not be obtained without the vehicle sinkage measurement[5]. Hence, by using the vehicle sinkage the tracked vehicle performance in term of motion resistance and power consumption has been measured on swamp peat and the results for the tracked vehicle with an additional track mechanism are compared to the tracked vehicle without the additional track mechanism to show the improvement. The sinkage experienced by the tracked vehicle with an additional track mechanism compared to the tracked vehicle without it and the maximum sinkage that should be experienced by the tracked vehicle is shown in Fig. 2. In previous studied, it is found that the mat thickness of swamp peat which is 0.070 m is the maximum sinkage that can be experienced by the vehicle, where the vehicle can be moved as long as the sinkage does not go over it[9]. While, the effect of the vehicle sinkage towards the vehicle motion resistance and power consumption are shown in Fig. 3 and 4, respectively.

In Fig. 2, the tracked vehicle with an additional track mechanism seems to provide more ground contact area on the swamp peat which reducing the ground contact pressure and reduced the sinkage of the tracked vehicle. Another word, the sinkage of the tracked vehicle reduced as the ground contact area of the tracked vehicle increased. As could be seen

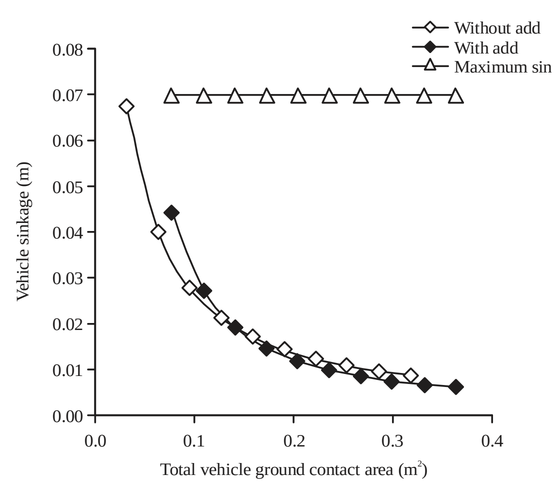

Fig. 2: Vehicle sinkage without and with an additional track

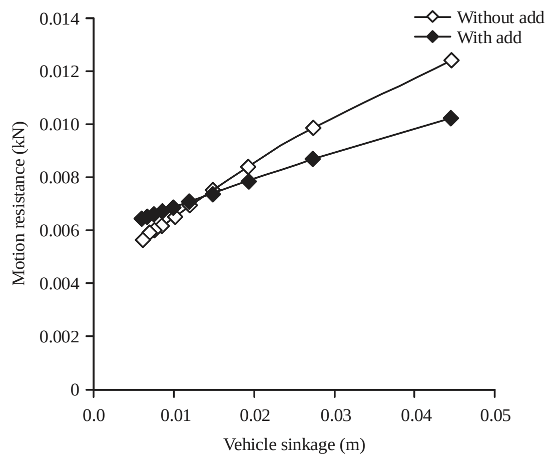

Fig. 3: Effect of vehicle sinkage on motion resistance

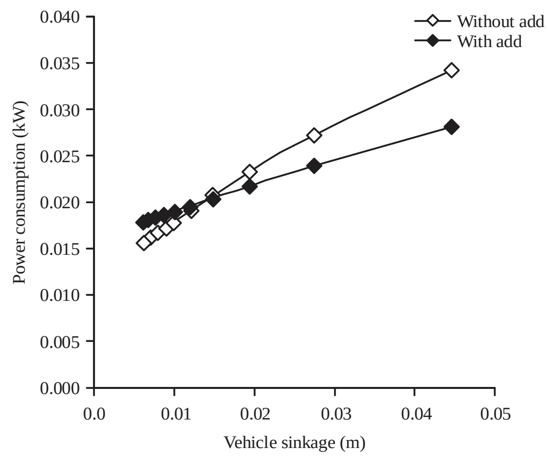

Fig. 4: Effects of vehicle sinkage on power consumption

in the graph, the sinkage of the tracked vehicle without the additional track mechanism is varied from 0.0087-0.0675 m, which means it nearly reaches up to the maximum sinkage which is not good for the tracked vehicle in order to move smoothly. When the additional track mechanism is implemented in the middle frame of the tracked vehicle, the sinkage of the tracked vehicle has been reduced from 0.0675-0.444 m below the maximum sinkage value. This result proves that the implementation of the additional track mechanism has enhanced the movement of the tracked vehicle as the vehicle did not sink to much in the swamp peat during the operation. Through the results of the vehicle sinkage, the motion resistance and power consumption are calculated in order to obtain the tracked vehicle performance for with and without the additional track mechanism using the developed mathematical model.

In present study, it is found that the vehicle sinkage has significantly affected the motion resistance and the power consumption as they are related directly towards each other[5]. Based on the Fig. 3, the motion resistance of the tracked vehicle crossing the swamp peat terrain is increased with the increasing of the vehicle sinkage. The tracked vehicle tend to sink in the swamp peat due to the swamp peat characteristic which is submerged and contain the undecomposed log[2]. These obstacles have slow down the movement of the tracked vehicle during the operation which is why there are still no offers of the vehicle that can effectively work on swamp peat terrain. From the line graph, the motion resistance is gradually increased at the early stage of the sinkage from 0.006-0.01 m for both tracked vehicle with an additional track mechanism and without it. Then, the vehicle experience more motion resistance when the vehicle sinkage is over 0.014 m. At the early sinkage, the motion resistance for tracked vehicle without the additional track experience less motion resistance. However, the results changed drastically when the sinkage at 0.019 m. This condition occurred probably because of no support that can avoid the tracked vehicle from be sunk in the swamp peat. Different from the tracked vehicle with an additional track mechanism, the additional track would be unfolded when the tracked vehicle sinkage experienced the sinkage and directly support the vehicle from being sunk in the swamp peat terrain during the operation. As the conclusion, higher in sinkage does effect the increasing of the motion resistance[3].

The same pattern applied for the power consumption of the tracked vehicle with an additional track mechanism and without the additional track. The line graph in Fig. 4 shows that the power consumption also increased with the increasing of the vehicle sinkage. This is because the power consumption is optimized from the compaction motion resistance and internal motion resistance of the tracked vehicle[10]. The power consumption of the tracked vehicle without the additional track is varied from 0.015 up to 0.034 kW while for tracked vehicle with the additional track mechanism is varied from 0.017-0.028 kW. Even though the power consumption for the tracked vehicle with additional track experience higher power consumption at the early sinkage, the power consumption become lesser as the sinkage is increased. This result is totally vice versa to the tracked vehicle without the additional track. This might due to the support given by the additional track during the operation where the vehicle can move like on the normal ground surface even when it experienced the sinkage in the swamp peat. Hence, only small amount of power needed to operate the tracked vehicle with an additional track. Furthermore, the additional track mechanism also did not require any power source to operate it as it can move along with the main track. While the tracked vehicle without the additional track needs more power in order to overcome the obstacles faced during the operation on swamp peat.

CONCLUSION

Vehicle sinkage gives a significant influence on the development of the tracked vehicle with and without an additional track mechanism. In addition, the vehicle needs to encounter the obstacles in swamp peat in order to be effectively operated. From the result obtained in this study, tracked vehicle with an additional track mechanism experienced less sinkage compared to the tracked vehicle without an additional track. Next, the vehicle motion resistance and power consumption is increased when the vehicle sinkage increased with 0.0102 kN and 0.0283 kW for each of them. Hence, the consideration on vehicle sinkage is important in designing the best swamp peat vehicle and the implementation of the additional track mechanism would help in reducing the sinkage of the vehicle.

SIGNIFICANCE STSTMENTS

- Existing tracked vehicle could not operate effectively over swamp peat terrain. In order to overcome the limitation of the existing tracked vehicle, the tracked vehicle with an additional tracked system has been designed
- Tracked vehicle performance (in term of motion resistance and power consumption) is investigated using the tracked vehicle sinkage
- Compare the results with other existing tracked vehicle
- Tracked vehicle with an additional track system would be the pioneer in the field of off-road vehicle. Therefore, future studies in this field should be sited for their bench marking
- Tracked vehicle with an additional track system is completely new concept in field of tracked vehicle system

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