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MINIMIZATION OF POWER LOSSES BY TRACTION-TRANSPORTATION VEHICLES AT MOTION OVER A BEARING SURFACE THAT UNDERGOES DEFORMATION

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Дослідження присвячено розробленню методу мінімізації втрат потужності тягово-транспортних засобів при русі по опорній поверхні з утворенням колії. Метою даного дослідження є підвищення тягового коефіцієнту корисної дії позашляхових тягово-транспортних засобів шляхом визначення та мінімізації втрат потужності на утворення колії на опорній поверхні під впливом ходових частин засобу. Підвищення коефіцієнту корисної дії тягово-транспортних засобів, котрий складає 55÷65 %, є пріоритетним напрямом розвитку механізації сільського господарства. Частина втрат, які залежать від конструкції засобу, в процесі експлуатації майже не контролюється. Але на суттєві втрати в ходових системах, які доходять до 20 %, можна впливати. Суть впливу полягає в узгоджені налаштування ходових систем тягово-транспортних засобів із станом опорної поверхні. Зокрема, в процесі даного дослідження був проведений аналіз величин потужностей, що витрачаються на переміщення елементів системи «остов машини – підвіска – ходова система – опорна поверхня, яка деформується» на підставі визначення силових та кінематичних факторів.

На підставі прямих вимірювань визначаються втрати потужності ходовими системами на утворення колії на опорній поверхні та переміщення елементів ходової системи. Запропоновано визначати потужність, яка витрачається на утворення колії здійснювати шляхом множення частки сили ваги, яка припадає на відповідний рушій на швидкість руйнування опорної поверхні. На підставі отриманих результатів та аналізу експериментальних даних зроблено такий висновок. Запропонована методика визначення втрат потужності на утворення колії тягово-транспортними засобами на опорній поверхні дозволяє обґрунтовувати вибір параметрів ходових систем з метою підвищення тягового коефіцієнту корисної дії

Ключові слова: тягово-транспортний засіб, ходова система, втрати потужності, сніговий покрив

1. Introduction

Improving a coefficient of efficiency (EC) of traction-transportation vehicles (TTV) is a priority in the development of mechanization of agriculture. It is known that at present the traction EC of tractors is 55÷65 % [1, 2]. Therefore, part of power losses is very significant. Losses are due to many factors, specifically, a rather high percentage of losses is predetermined by the design of a traction-transportation vehicle. Part of the losses that are related to the structure of a vehicle are not controlled during operation. However, those significant losses in running systems that amount to 20 % can be managed. Control over them implies adjusting the settings of running systems in the traction-transportation vehicles to the condition of a bearing surface. Specifically, it is possible to minimize power losses in traction-transportation vehicles during motion over a bearing surface resulting in the formation of a rut. That would make it possible to increase the value for a traction efficiency coefficient; therefore, it is a relevant task to construct a method that could minimize power losses by traction-transportation vehicles at rut formation.

2. Literature review and problem statement

Paper [1] reports results of experimental research into determining the share of distribution of energy absorption by tires and shock absorbers in the system «wheel – suspension». The traction-transportation vehicle examined was the military armored vehicles. It is shown that the characteristics of power redistribution are significantly affected by both the characteristics of shock absorbers and the air pressure in tires. Though the authors stated the task on developing a method to reduce power losses, they did not suggest ways to solve it. Article [2] considered modern structures of TTV for various purposes. There are several approaches to reducing power losses. Work [3] analyzed the redistribution of power depending on a change in their mass and the properties of a bearing surface. In order to reduce power losses by off-road vehicles and trailers for agricultural purposes, it is proposed to monitor air pressure in tires. Authors of paper [4] additionally proposed taking into consideration the number of supporting wheels at road trains with hoisting equipment and tractors with double or even triple sets of wheels. Study [5] shows the way in which pneumatic elastic elements in suspension systems are capable of adapting their rigidity depending on a change in the TTV mass. Work [6] analyzed changes in the shock absorbers' coefficient of damping depending on the condition of a microprofile of the bearing surface. However, papers [2–6] failed to address the issue on minimizing power losses when forming a rut over a bearing surface under the influence of running gears of a traction-transportation vehicle. This issue was considered in studies [7–9]. According to the classic theory of TTV motion over a bearing surface that undergoes deformation, the magnitude of power consumed for the deformation of the bearing surface is determined based on determining the force of motion resistance by using coefficients of motion resistance by different types of engines over various bearing surfaces [6]. Known paper [8] emphasized energy processes that occur when a wheel moves over a bearing surface that undergoes deformation. However, study [9] demonstrated that in terms of practical calculations the constructed dependences are rather complicated, because one must consider too many parameters when building a mathematical model. Therefore, there is a task to construct a method that would simplify a mathematical model and reduce computational complexity of calculations. In addition, works [7–9] did not substantiate the selection of parameters for running systems. Thus, the above allows us to argue about the need to undertake a research into the possibility to minimize power losses by traction-transportation vehicles at rut formation.

3. The aim and objectives of the study

The aim of this study is to devise a technique to minimize power losses by traction-transportation vehicles when moving over a bearing surface resulting in rut formation. This is possible by improving the traction efficiency coefficient for off-road traction-transportation vehicles under the influence of running gears in a traction-transportation vehicle.

To accomplish the aim, the following tasks have been set:

– to determine the power spent to form a rut when moving over a bearing surface that undergoes deformation;

– to study variation limits for values of the power required to form a rut depending on different parameters for motion and different parameters that characterize a traction-transportation vehicle.

4. Determining the power used to form a rut

Fig. 1 shows a sequence of basic elements in the system at which power is lost along a path from the internal combustion engine (ICE) to forming the traction power. Part of the losses that are related to the structure of a TTV are almost not controlled during operation. However, those significant losses in running systems that amount to 20 % can be managed.

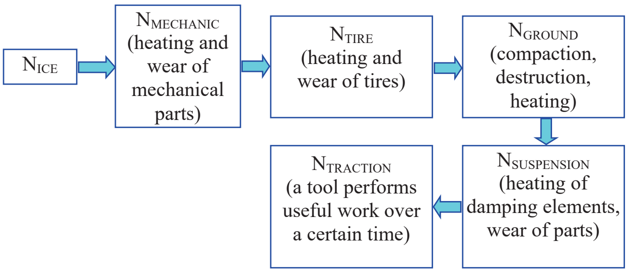

Fig. 1. Losses of mechanical power during transmission from ICE to the traction device of TTV

The essence of influence implies adjusting the settings of TTV running systems to the condition of a bearing surface. One of the criteria for adjustment is to determine power losses at elements in the system «frame – suspension – wheels – bearing surface».

Based on the research into determining pressure in soil using the procedures from of geophysical electric exploration (a four-electrode Schlumberger installation as part of the auto-compensator of electric prospecting AE-72) [10, 11], we established under actual conditions the presence of an elastic component of deformation related to the running a system of tractor T-25, as shown in Fig. 2.

It was established in the course of study at a research area of the National Scientific Center «Institute of Mechanization and Electrification of Agriculture», Ukraine, Kyiv oblast, Vasylkivski region, village Glevakha, (NNC «IMESG) that the elastic component of deformation (Δp) under certain conditions for the state of soil at a depth of 20 cm is 20 % of the maximum deformation (Δmax). In addition, the elastic component of deformation is 25 % of the plastic deformation.

A significant decrease in soil deformation under repeated loading is confirmed in papers [12, 13].

It is common knowledge that mechanical power N is determined from the scalar product of the force vector by the vector of velocity (1).

$$N = F \cdot V \cdot \cos\alpha, \tag{1}$$

where F is the magnitude of force; V is the speed magnitude; α is the angle between the force and velocity vectors.

Thus, the power spent to form a rut by a TTV running system will depend on the force that creates this rut and the rate at which it forms.

The force under whose influence a rut forms under stationary conditions when moving over a flat horizontal bearing surface is the force of weight – G, as shown in Fig. 3.

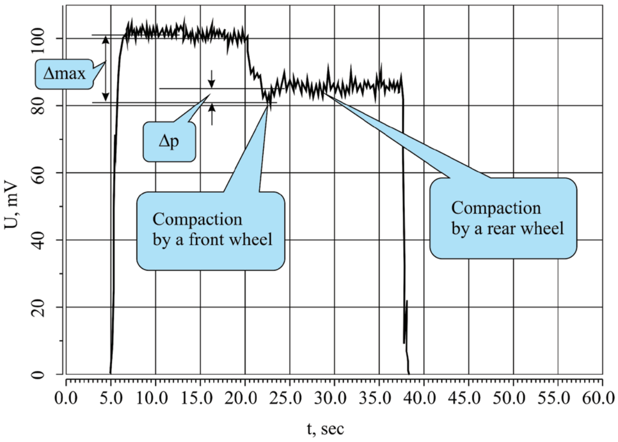

Fig. 2. Example of determining relative magnitudes of elastic and plastic deformation of soil under the influence of a suspension system of tractor T-25

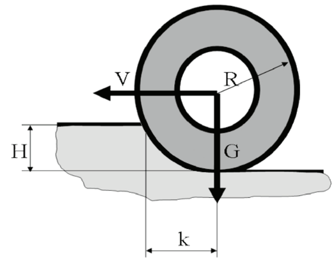

Fig. 3. Determining the rate of rutting

Rate at which a rut of depth H forms represents its differential over time – $V_k = dH/dt$. It depends on the following parameters:

– the depth of a rut,
– TTV motion speed (V),
– the radius of wheel rolling (R).

To determine the average value for V_k, we assume the following:

$$V = \text{const}, \quad R = \text{const}.$$

Then the time of rut formation depends on the length of compaction distance k and motion speed V, that is:

$$t = \frac{k}{V}. \tag{2}$$

By using geometrical transformations, we determine from Fig. 4 the dependence of k on R and H.

$$k^2 = R^2 - (R - H)^2; \tag{3}$$

$$k = \sqrt{2RH - H^2}; \tag{4}$$

$$t = \frac{\sqrt{2RH - H^2}}{V}; \tag{5}$$

$$V_k = \frac{HV}{\sqrt{2RH - H^2}}; \tag{6}$$

$$N_k = \frac{GHV}{\sqrt{2RH - H^2}}. \tag{7}$$

Expression under the root must be a positive magnitude, that is:

$$2RH - H^2 \succ 0,$$

then

$$2R \succ H. \tag{8}$$

Actual values for a rut depth gauge cannot exceed the clearance of TTV and range within $0 \le H \le 0.4$ m.

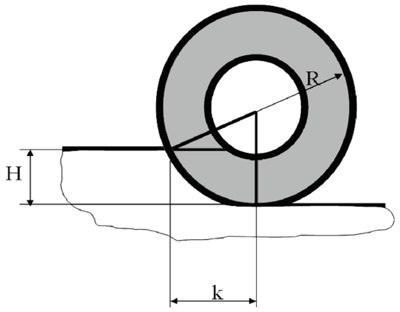

Fig. 4. Determining the length of compaction distance *k*

Thus, the radius of a wheel can also accept values from 0 to ∞; however, for small values of the radius and the rut depth, one must follow inequality (8).

Calculations based on formulae (1) to (8), their comparison with known results, as well as simulation, were conducted in a cloud-based environment [14, 15].

5. Studying variation limits of values for the power required to form a rut

Fig. 5, 6 show diagrams for calculating the power required to form a rut.

Diagrams in Fig. 6 show that the power increases rapidly over first 5 cm of the rut depth formation, and then there is an almost linear dependence. Note the influence of speed on the power of rut formation (Fig. 6). Thus, assuming that each wheel of TTV with a wheel formula of 4K4b and a mass of 6 t forms a rut of depth 0.15 m, then motion at speed 15 m/s (54 km/h requires power 80×4=320 kW (435 h.p.).

The three-dimensional dependences in Fig. 7, 8 show a greater curvature in the dependence of power magnitude on the radius of a wheel than the dependences on a rut depth. Hence, we can draw a conclusion on selecting the maximum possible diameter of front wheels in TTV with the wheel formula 4K2a and 4K4a. The influence of weight and motion speed of TTV on the magnitude of power to form a rut is shown in Fig. 9.

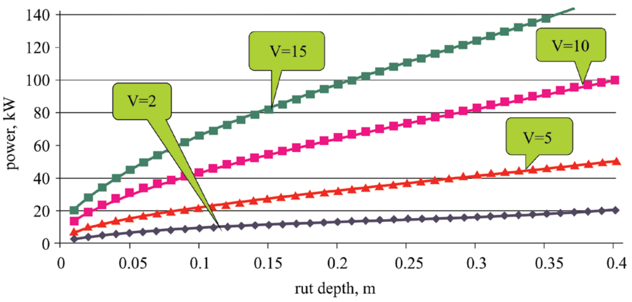

Fig. 5. Dependence of the power required to form a rut at different motion speeds and $R=0.64$ m, $G=15$ kN

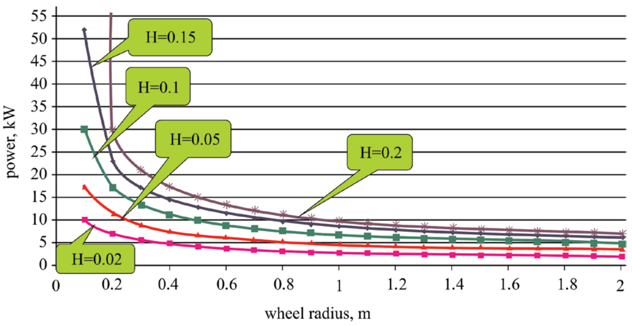

Fig. 6. Dependence of magnitude of the power required to form ruts of different depth on the radius of a wheel

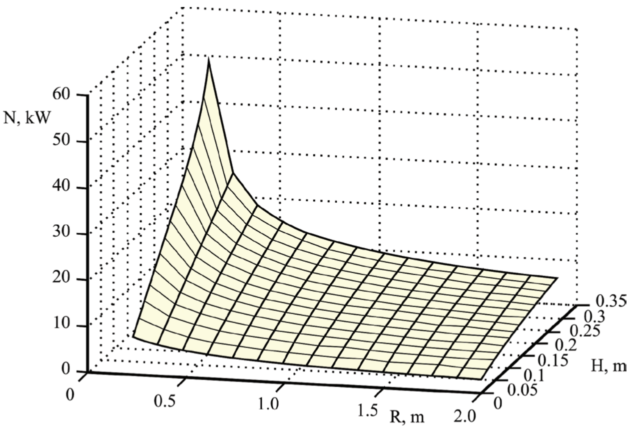

Fig. 7. The surface of dependence of the power required to form a rut on the rut depth and the radius of a wheel at $G=15$ kN, $V=2$ m/s

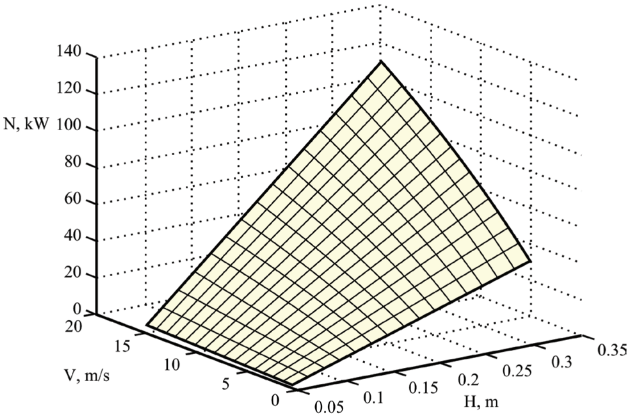

Fig. 8. The surface of dependence of the power required to form a rut on the rut depth and motion speed at $G=15$ kN, $R=0.64$ m

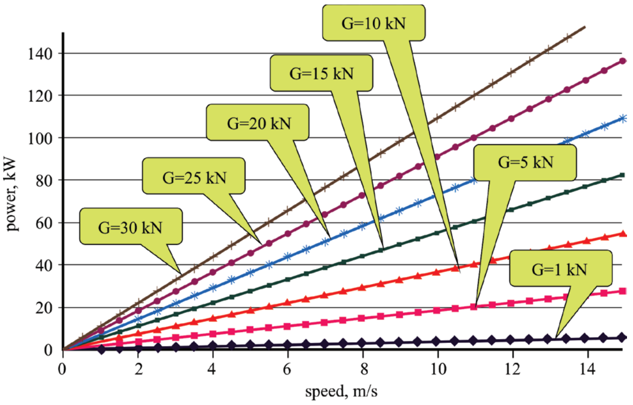

Fig. 9. The family of dependences of magnitudes of power to form a rut on motion speeds and a normal force that forms a rut

Dependence (6) demonstrates that the magnitude of the mean rate of rut formation of a rut V_k is affected by wheel R. For a perfect caterpillar mover $R=\infty$, then $V_k=0$ and $N_k=0$. In this case, V_k, instead of magnitude k, is substituted with the magnitude of the bearing surface of a caterpillar mover [15].

6. Verification of the proposed method under conditions of deep snow cover

In our tests, we used a caterpillar TTV for geophysical purposes [16], which is shown in Fig. 10. A given TTV was tested under conditions of deep snow cover – up to 1.5 meters, which can be seen from Fig. 11.

Under static conditions (when parked), the running gear of caterpillar movers, both in energy and technological modules, was leveled parallel to the bearing surface, which is shown in Fig. 12. When moving, the front part of the caterpillar mover in power module rose relative to the rear part of the same mover, as shown by the photograph in Fig. 13.

Thus, the rate of forming a deep enough rut (the clearance of the running gears in energy and technological modules was increased to 0.45 m) was rather low. This made it possible for the connected four-wheel caterpillar TTV with a full mass larger than 18 tons to move steadily in the marshland variant of the mover's tracks. In this case, the motion was enabled in the second or first gear of the adapted motor-gear assembly of tractor T-150. Steady motion was executed regardless of the snow cover depth.

Fig. 10. Testing the coupled caterpillar vehicle

Fig. 11. Dive into a snow cover

Fig. 12. Horizontal position of the caterpillar mover of immobile TTV over a deep snow cover

Fig. 13. Gradual immersion of the caterpillar mover into a snow cover reduces the power to form a rut

A similar situation occurred when driving the bulldozer based on tractor T-130 with a marshland caterpillar mover. Under conditions of a deep snow cover, forward movement was impossible because of the significant forward displacement of the center of mass of the tractor relative to the mover's bearing part. Under this mode, the rate of rut formation was great. And when driving backwards, the tractor together with the mover were set at a certain angle to the bearing surface, thereby gradually pushing the snow cover when forming a rut. Under this motion mode, the power spent to form a rut was much lower: the engine power of 130 h.p. was enough to ensure the stable movement of the tractor. This phenomenon is confirmed by known studies that employed a special self-propelling crawler truck with variable parameters [16].

Based on the measurements of relative speeds of the suspension elements and the results from testing a damping coefficient for amortization devices at the bench, we can determine the power, which is converted into heat via shock absorbers. Upon determining the power of all constituent elements in the system, the EC of the system is derived from known formulae.

6. Discussion of results of studying power losses to form a rut by traction-transportation vehicles

The proposed technique to study power losses related to forming a rut by traction-transportation vehicles on a bearing surface has made it possible, based on elementary calculations, to substantiate the choice of parameters for running systems.

A special feature of the proposed solution is the possibility to choose those values for the basic parameters of running systems that make it possible to improve the traction coefficient of efficiency. By increasing the traction EC we were able to reduce power losses to form a rut by traction-transportation vehicles on a bearing surface.

The merits of this research compared to existing analogues are the possibility to minimize power losses to form a rut on a bearing surface under the influence of the running systems of a traction-transportation vehicle. In contrast to most existing classic approaches, the proposed technique makes it possible to define the limits of variation in the values for the power required to form a rut. In addition, in the simulation of the movement of a wheel over a bearing surface that undergoes deformation, as opposed to existing classic approach, we have significantly reduced computational complexity in calculations. The results obtained are especially important for the conditions of TTV motion over soil, which is prone to significant deformation resulting in the formation of a deep rut. For example, it could be the movement of TTV under conditions of a deep snow cover.

The proposed technique provides advantages in determining the power losses to form a rut by traction-transportation vehicles; it is, however, applicable only for the motion of a bearing surface that undergoes strong deformation.

Further advance of the present research implies the development of a simulation model of TTV motion over soil, which is prone to significant deformation with the formation of a deep rut. That would help define the limits of variation in the parameters of TTV running systems without conducting practical tests. One can also explore changes in the magnitudes of power spent to displace elements in the system «machine's frame – suspension – running system – bearing surface that undergoes deformation», based on determining the force and kinematic factors.

7. Conclusions

1. We have proposed and substantiated a technique for analytical calculation in order to determine the power used in the formation of a rut at motion over a bearing surface that undergoes deformation. It is shown that it grows

exponentially at the start of rut depth formation, followed by an almost linear dependence. We have noted a significant influence of speed on power in the formation of a rut. Specifically, it is shown that a gradual immersion of the caterpillar mover into a snow cover at low speeds (up to 4 m/s) decreases the power required for rut formation by up to 15 %.

2. We have derived analytical dependences to calculate the limits of variation in the values for the required power to form a rut when moving over a bearing surface that undergoes deformation. Specifically, for practical calculations, we use both the parameters for motion (a speed magnitude, direction of motion, a wheel rolling radius) and those that characterize a traction-transportation vehicle (weight of TTV, magnitude of the bearing surface, air pressure in wheels). That makes it possible, at the stages of design and under operation mode, based on elementary calculations, to substantiate the choice of parameters for running systems in order to improve the traction efficiency coefficient. In turn, this contributes to a decrease, by up to 20 %, in the power losses to form a rut at the bearing surface that undergoes deformation.

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