DETERMINATION OF RATIONAL OPERATING MODES OF OPERATION OF TRACTOR AGRICULTURAL TIRES

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Abstract: The efficiency of wheeled agricultural tractors when performing traction technological operations is characterized by two aspects. The first of these is traction efficiency, which mainly depends on the coupling weight of the tractor and the perfection of its running system. Another aspect is environmental friendliness, which is determined by the level of compaction impact on the soil. In general, these aspects are oppositely directed. That is, an increase in traction efficiency requires an increase in the grip weight and, as a consequence, an increase in the radial load on the tires and the internal pressure in them. This leads to an increase in tire pressure on the ground and deterioration in their environmental performance. As a result of excessive soil compaction, the yield of agricultural crops is significantly reduced. To solve this problem, it is necessary to reduce the tire pressure on the ground, which can be achieved by reducing the grip weight or developing and introducing new innovative tire designs. But, even new innovative tire designs have corresponding limitations due to the radial load interval, internal pressure, travel speed and the amount of torque on the wheel. These restrictions form the area of possible operating modes of tractor tires, individual sections of which differ significantly in terms of traction efficiency and environmental friendliness. Within the limits of possible modes of operation of the tire, operating modes must be implemented in areas of high efficiency and environmental friendliness.
The materials of this article are basic in the study and substantiation of rational operating modes of tractor agricultural tires, and also provide prerequisites for the formation of recommendations for improving the traction efficiency and environmental friendliness of wheeled tractors.
Keywords: wheeled tractor, tire inflation pressure, traction efficiency, environmental friendliness, tire radial load.

1. Introduction

The study of the traction efficiency of wheeled tractors provides for the determination of indicators of the interaction of the tractor tire with the soil, which is influenced by the magnitude of the radial load, internal pressure, the area of the contact patch and the characteristics of the soil itself. The simplest and most effective way to increase the traction properties of a tractor is the use of ballasting. When ballasting, by increasing the coupling weight, the traction properties of the tractor are improved. However, the increased weight of the tractor requires increasing the inflation pressure in the tires to the required level. The cumulative increase in radial load and tire inflation pressure will inevitably lead to an increase in ground pressure. Thus, the environmental friendliness of the wheeled tractor deteriorates.

An effective means of simultaneously increasing traction performance and environmental friendliness of tractors is to equip with elastic tires with an increased area of contact with the ground. This is evidenced by the direction of numerous research and development in the field of creating innovative designs of tractor tires and systems for regulating the internal air pressure in them.

However, in any case, even the use and operation of innovative highly elastic tires does not fully solve the contradiction between traction efficiency and environmental friendliness of the tractor. Therefore, the substantiation of rational operating modes of operation of tractor agricultural tires is an urgent task aimed at solving this contradiction.

2. Materials and Methods

The study of traction efficiency is given in [1–4], where there is a significant effect of the radial load and internal pressure in the tire on the performance of tractors. The authors [1–4] note the positive effect of reducing the internal pressure from 160 kPa to 60 kPa, which is manifested in a decrease in fuel consumption to 14–16 %, an increase in traction properties by 12–30 % (at a constant tractor weight). In works [1–4], a positive effect was found during the operation of tractor tires in terms of internal pressure close to the lower limit – 60 kPa. But the authors of [5] point to a positive effect manifested in the improvement of the environmental performance of modern tires with a decrease in pressure from 80 kPa to the recommended 60 kPa and predict its further improvement with a decrease in internal pressure to 40 kPa. In [6] it is shown that with a normal slip coefficient of 7–15 %, an increase in internal pressure in the range of 100–240 kPa is accompanied by an increase in fuel consumption and slip. Along with this, the authors of [6] note a decrease in slipping and an increase in fuel consumption during ballasting. But in these works [1–6], the authors do not investigate the relationship of such parameters as radial load, internal tire pressure, maximum ground pressure, slip coefficient, rolling resistance, specific traction force, coefficient of adhesion weight utilization, which is fully characterize the efficiency and environmental friendliness of the tractor and determine the optimal operating modes of tractor tires.

Therefore, within the framework of this work, the aim is to establish the relationship between the listed indicators and substantiate the rational operating modes of a single tractor tire operating with normal slipping up to 15 %.

3. Results

Determination of efficiency indicators of a single tractor tire was carried out by calculation, taking into account the impact on the environment in the form of maximum pressure on the ground [7]. The proposed technique can be extended to substantiate the prospect of using doubling or building tires [8]. The modified dependence [9] of tangential stresses in the soil in the form of the dependence of the Gross Traction Ratio ψ_k on the slipping coefficient δ (1) was taken as the base. The Net Traction Ratio φ_k, Motion Resistance Ratio f_n and other indicators were also determined [10]:

$$\psi_k = \left(\frac{1{,}5 \cdot c_c}{q_{\max} \cdot k_D} + \mathrm{tg}\varphi\right) \times \left\{1 - \frac{k_c \cdot (1-\delta)}{\delta \cdot a_k} \cdot \left[1 - \exp\left(-\frac{\delta \cdot a_k}{k_c \cdot (1-\delta)}\right)\right]\right\}; \quad (1)$$

$$\psi_k = \frac{P_{GT}}{G_k}; \qquad (2)$$

$$P_f = 0.81 \cdot \frac{k_0 \cdot k_N}{100 \cdot \sqrt{a_k \cdot b_k}} \cdot b_k \cdot h_s^2; \qquad (3)$$

$$P_{NT} = P_{GT} - P_f; \qquad (4)$$

$$\varphi_k = \frac{P_{NT}}{G_k}; \qquad (5)$$

$$f_n = \psi_k - \varphi_k; \qquad (6)$$

$$\eta_f = \frac{P_{GT} - P_f}{P_{GT}} = \frac{P_{NT}}{P_{GT}}; \qquad (7)$$

$$k_t = \frac{G_k}{[Q]} \cdot 100\,\%; \qquad (8)$$

$$G_k = \frac{f_t^2}{c_1 + c_2 \cdot \dfrac{f_t}{p_t + p_0}}; \qquad (9)$$

$$q_{\max} = \frac{1{,}5 \cdot G_k}{k_\Sigma \cdot k_D \cdot F_k}; \qquad (10)$$

$$F_k = \frac{\pi}{4} \cdot a_k \cdot b_k, \qquad (11)$$

where c_c, k_c, φ_c – the coefficients characterizing the properties of the soil (the soil cohesion, the soil shear deformation modulus, the angle of soil shear resistance) $q_{\max}$ –the maximum pressure on the soil of the tire; k_D – coefficient depending on the outer diameter of the tire and characterizes the uneven distribution of pressure on the ground; G_k – radial load on the tire; P_{GT} – gross traction; P_f – motion resistance; a_k, b_k – length and width of the contact patch; k_0 – coefficient of volumetric crushing of the soil; h_s – rut of depth; P_{NT} – net traction η_f – pull ratio, k_t – coefficient characterizing the tire load ratio in relation to the permissible load [Q] in %; c_1, c_2, p_0 – constant coefficients for the tire; f_t – the radial deflection of the tire; p_t – the internal pressure in the tire; k_S – coefficient that takes into account the conditions of the wheel; F_k – the area of the tire contact patch.

When determining the maximum ground pressure, a model of the universal tire characteristic was applied (9). The calculation results (1)–(11) are shown on the example of 800/70 R38 tire (**Fig. 1**).

The field of possible tire operating modes (**Fig. 1**) is limited from above by the values of the permissible load at k_t=100 %, and on the left and right by the minimum (60 kPa) and maximum (160 kPa) internal pressure in the tire, respectively.

4. Discussion

Let's consider the indicators of traction efficiency and environmental friendliness of the tire at the limiting value of the slipping coefficient of 15 % [6] when interacting with an average loam with a moisture content of 18–22 %. The operating conditions of the tire must be within the range *E* (**Fig. 1**), where the radial load G_k is 80–100 % of the permissible [*Q*]. This is due to the redistribution of the coupling weight of the tractor with an increase in the traction force on the hook. In area *E*, the best traction performance (ψ_k, φ_k) is observed at point *A* (**Fig. 1**). With an increase in the radial load, the indicated traction indicators increase with a simultaneous increase in the rolling resistance f_n. Increasing the radial load at a constant tire inflation pressure p_t has a positive effect on traction efficiency even when rolling resistance is increasing. The maximum ground pressure $q_{\max}$ increases more rapidly with an increase in the internal pressure p_t than the radial load G_k. An increase in the maximum ground pressure in accordance with (1) negatively affects the Gross Traction Ratio ψ_k.

The qualitative picture of the traction efficiency and environmental friendliness of the tire allows to recommend equipping the tractor with tires in such a way that the static load on the front tires is close to mode *A*, and the rear tires – to mode *B* (**Fig. 1**). The implementation of such operating modes of tires will allow to obtain high efficiency and environmental friendliness of the tractor as a whole.

Thus, the operation of an 800/70 R38 tire with a minimum internal pressure of 60 kPa in area *E* allows the use of Net Traction Ratio φ_k to be about 0.51, and at a maximum pressure of 160 kPa – only about 0.45. Therefore, the traction efficiency at 60 kPa is correspondingly higher. The situation is similar with the maximum ground pressure. Reducing the internal pressure in the tire from 160 kPa to 60 kPa makes it possible to reduce the maximum ground pressure $q_{\max}$ from 200 kPa to 110 kPa, that is, 1.8 times.

The prospect for further research is the implementation of the proposed theoretical results in the simulation of traction dynamic tests, for example, PowerMix field cycles [11]. In addition, the issue of rational equipping the tractor with twin tires cannot be ignored.

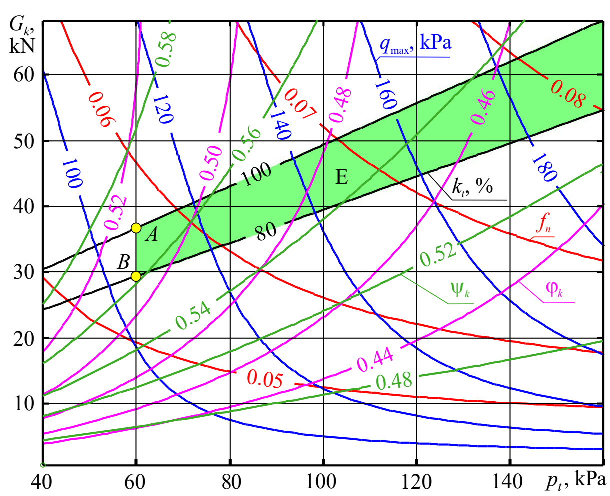

Fig. 1. Indicators of traction efficiency and environmental friendliness of 800/70 R38 tires

5. Conclusion

Thus, it is analytically established that the rational operating modes of tractor tires are observed in the area of the minimum permissible internal pressure. According to estimates, using the 800/70 R38 tire as an example, operation at a minimum internal pressure of 60 kPa compared to the maximum (160 kPa) allows increasing the coefficient of Net Traction Ratio φ_k from 0.45 to 0.51, and reducing the maximum ground pressure $q_{\max}$ by 1.8 times from 200 kPa to 110 kPa.

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