Matching the Traction Qualities of Agricultural Mobile Power Vehicles with the Permissible Maximum Pressure on the Soil

Aleksandr V. Lavrov,
Ph.D.(Eng.), leading researcher,
e-mail: vimlavrov@mail.ru;
Vladimir G. Shevtsov,
Ph.D.(Eng.), leading specialist;

Aleksandr V. Rusanov,
chief specialist;
Vera A. Kazakova,
junior researcher

Federal Scientific Agroengineering Center VIM, Moscow, Russian Federation

Abstract. Modern highly mechanized agricultural production is characterized by the incompatibility of simultaneous matching of the maximum pressure of agricultural mobile equipment movers on the soil and the possibility of increasing the tractors energy saturation when equipping them with existing wheel engines. (*Research purpose*) To coordinate the maximum pressure on the soil with the permissible norms, weight utilization factors and the level of tractors energy saturation. (*Materials and methods*) The authors used a calculated method for determining the maximum pressure on the soil using a universal tire characteristic. (*Results and discussion*) The authors found that when performing spring works on closing moisture and sowing row crops at a maximum pressure of 80 kilopascals, corresponding to all types of soil, the most mass universal row tractor Belarus 1020 had a maximum pressure of 150 kilopascals, which was 70 kilopascals higher than the permissible one for the corresponding crop shortage. They found that replacing ordinary tires with agrophilic tires could increase the area of the contact spot by 16 percent, while reducing the coefficient of unevenness and increasing the coefficient of use of the adhesion weight. The main condition for replacing ordinary tires with agrophilic tires was to keep the traction force unchanged. (*Conclusions*) Summarizing the results of the research as agrophilic direction, ensuring the compliance impacts on soil and positively solving the problems of saturation, it is possible to recommend the development of navigation systems in achieving utilization hitch weight equal to 0.5 (low tire pressure), equal to 0.6 (rubber joint with torsion bar suspension) and 0.7 (rubber track). It was found that the conducted research, taking into account the available data on traction tests of the T-250 tractor, would allow to include an agrophilic concept with a hypothetical dependence of the adhesion weight use factor on the longitudinal unevenness coefficient in the revised State Standard 27021-86 "Agricultural and forestry Tractors. Traction classes".

Keywords: power tool, coupling weight, agrophilic tire, ordinary tire, maximum pressure on the soil, longitudinal unevenness, traction force.

Согласование тягово-сцепных качеств движителей сельскохозяйственных мобильных энергетических средств с допустимым максимальным давлением на почву

Александр Владимирович Лавров,
кандидат технических наук, ведущий научный сотрудник, e-mail: vimlavrov@mail.ru;
Владимир Георгиевич Шевцов,
кандидат технических наук,
ведущий специалист;

Александр Вадимович Русанов,
старший специалист;
Вера Александровна Казакова,
младший научный сотрудник

Федеральный научный агроинженерный центр ВИМ, Москва, Российская Федерация

Реферат. Современное высокомеханизированное сельскохозяйственное производство характеризуется несовместимо-

9

СЕЛЬСКОХОЗЯЙСТВЕННЫЕ МАШИНЫ И ТЕХНОЛОГИИ • Том 14 • N3 • 2020   AGRICULTURAL MACHINERY AND TECHNOLOGIES • Volume 14 • N3 • 2020

стью одновременной реализации требований экологических организаций к максимальному давлению движителей сельскохозяйственной мобильной техники на почву и возможностей повышения энергонасыщенности тракторов при оснащении их существующими колесными движителями. (*Цель исследования*) Согласовать максимальное давление на почву с допустимыми нормами, коэффициентами использования сцепного веса и уровнем энергонасыщенности тракторов. (*Материалы и методы*) Использовали расчетный метод определения максимального давления на почву с помощью универсальной характеристики шины. (*Результаты и обсуждение*) Установили, что при выполнении весенних работ по закрытию влаги и проведению посева пропашных культур при допустимом максимальном давлении 80 килопаскалей, соответствующем всем типам почв, самый массовый универсально-пропашной трактор Беларус 1020 имеет максимальное давление 150 килопаскалей, что на 70 килопаскалей превышает допустимое при соответствующем недоборе урожая. Установили, что замена ординарных шин на агрофильные позволяет увеличить площадь пятна контакта на 16 процентов с одновременным уменьшением коэффициента неравномерности и увеличением коэффициента использования сцепного веса. Принципиальным условием замены ординарных шин на агрофильные служит сохранение неизменным создаваемого трактором тягового усилия. (*Выводы*) Определили оптимальные значения коэффициента использования сцепного веса: для шин сверхнизкого давления – 0,5, для резинометаллического шарнира с торсионной подвеской -- 0,6, для резиноармированной гусеницы – 0,7. Установили, что проведенные исследования с учетом имеющихся данных о тяговых испытаниях гусеничного трактора Т-250, позволят включить агрофильную концепцию с гипотетической (предполагаемой) зависимостью коэффициента использования сцепного веса от коэффициента продольной неравномерности в пересматриваемый ГОСТ 27021-86 «Тракторы сельскохозяйственные и лесохозяйственные. Тяговые классы».

Ключевые слова: энергетическое средство, сцепной вес, агрофильная шина, ординарная шина, максимальное давление на почву, продольная неравномерность, тяговое усилие.

Modern highly mechanized agricultural production is characterized by the incompatibility of the simultaneous implementation of the environmental organizations requirements for the maximum pressure of the agricultural mobile equipment propellers on the soil (State Standard R 58655-2019 replacing State Standard 26955-86) and the possibilities of increasing the tractors energy saturation when equipped with existing wheeled propellers (State Standard 27021-86) [1-4].

THE RESEARCH PURPOSE is to coordinate the maximum pressure q_{max} on the soil with permissible norms, coefficients of adhesion weight φ_c using and the level of tractors energy saturation.

MATERIALS AND METHODS. To solve this problem, it is necessary to conduct in-depth experimental studies of the longitudinal non-uniformity coefficient influence the pressure distribution over the tire K_2 contact area on the adhesion weight φ_c use coefficient for given slipping δ_{max} and maximum contact pressure qmax.

To coordinate the maximum pressure q_{max} on the soil with the permissible norms, the adhesion weight φ_c use coefficients and the energy saturation level, the authors used the calculation method for determining the maximum pressure on the soil using the universal characteristics of the tire, given in State Standard R 58656-2019 in combination with the results of actual traction tests of progressive wheel and tracked movers [5-7].

RESULTS AND DISCUSSION. As a result of the research, it was found that when performing spring work on closing moisture and sowing row crops at an admissible maximum pressure of 80 kPa, corresponding to all types of soils, the most massive universal row-crop tractor Belarus 1020 had a maximum pressure of 150 kPa, which was 70 kPa higher than permissible with a corresponding shortage of harvest (*Fig. 1*).

Based on the previous results, the authors considered the possibility of reducing the maximum pressure of the tractor, based on *Fig. 2* and formula (1), obtained taking into account that $q_{max}^{к} = \overleftarrow{q_{к}} \cdot K$; where $K_2 = 1.5$ was the coefficient of longitudinal non-uniformity of pressure distribution over the support area of the tire-soil contact [6, 8-14].

For new highly elastic tires K_2 could be specified when determined according to a method agreed with consumer, customer and tire developer representatives (State Standard R 58656-2019, replacing State Standard 26953-86. Agricultural mobile equipment. Methods for determining the impact of propellers on the soil).

$$\overline{q_к} = \frac{G}{F_{кп}}$$

where $G_к$ – mass that created a static load on the soil by a single wheel propeller; $F_{кп}$ – wheel contact area with soil, m^2.

10

СЕЛЬСКОХОЗЯЙСТВЕННЫЕ МАШИНЫ И ТЕХНОЛОГИИ • Том 14 • N3 • 2020   AGRICULTURAL MACHINERY AND TECHNOLOGIES • Volume 14 • N3 • 2020

Таблица 1								Table 1
TRACTION INDICATORS OF THE T-150K TRACTOR WITH VARIOUS TIRES								
Tractor model and its equipment	Operational weight, kg	Tractor transmission	Maximum traction power, kW (hp)	**Indicators at the highest tractive power**			Slipping,%	Adhesion weight use factor	Conditional traction efficiency
				Traction force, kN (kgf)	Speed, km/h	Specific fuel consumption, g / kWh (g / hph)			
Spring barley stubble									
T-150K on ordinary tires FD-14A 21,3R24	7970	2-1 2-2 2-3 2-4	65.2 (88,7) 69.5(94,5) 78.8(107,1) 83.2(113)	38.5(3925) 38.5(3925) 35.0(3570) 26.5(2700)	6.1 6.5 8.1 11.3	426(313) 423(311) 378(278) 353(260)	23.4 23.4 18.6 11.2	0.493 0.493 0.454 0.339	0.529 0.564 0.639 0.675
T-150K on dual tires FD-14A 21,3R24	9000	2-1 2-2 2-3 2-4	71.2(96,7) 79.1(107,6) 80.8(109,2) 83.3(113,1)	42.0(4280) 39.0(3980) 34.0(3470) 27.0(2750)	6.1 7.3 8.5 11.1	416(306) 382(281) 364(269) 331(244)	24.4 19.6 12.8 11.2	0.476 0.442 0.386 0.306	0.578 0.642 0.655 0.676
T-150K on oligomeric (agrophilic) tires 66×43-25 from "LIM"	8890	1-4 2-1 2-2 2-3	86.2(117,1) 95.6(129,8) 98.6(134,1) 94.8(128,7)	47.0(4790) 43.0(4380) 39.0(3980) 32.5(3310)	6.6 8.0 9.1 10.5	336(247) 312(230) 304(224) 298(220)	13.2 9.4 6.4 3.8	0.539 0.493 0.448 0.372	0.699 0.775 0.799 0.769

Then:

$$q_{max}^{\kappa} = \frac{G}{F} \cdot K_2. \tag{1}$$

At the same time, the adhesion weight use factor based on *table 1* (tests of tires of LIM company), take $\varphi_c^A = 0.5$, where φ_c^A – adhesion weight use factor of agrophilic tires, instead of $\varphi_c^o = 0.39$ where φ_c^o – adhesion weight use factor of ordinary tires corresponding to the old State Standard 27021-86.

At the same time, the authors assumed that $K_2^A = 1.2$, where K_2^A was the coefficient of agrophilic tires irregularity, instead of $K_2^o = 1.5$ where K_2^o – adhesion weight use

factor of ordinary tires.

The fundamental condition for replacing ordinary tires at $\varphi_c^o = 0.39$ with agrophilic ones at $\varphi_c^A = 0.5$ was to maintain a constant traction force created by the tractor:

$$P_{cr} = Const, \tag{2}$$

in accordance with the definition of adhesion weight use factor, was determined by the formula:

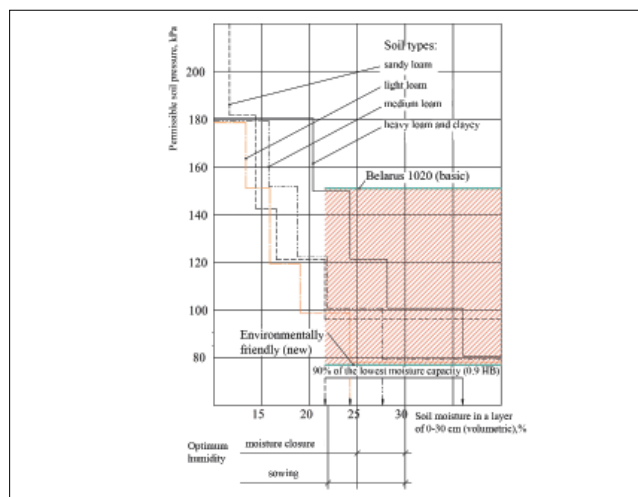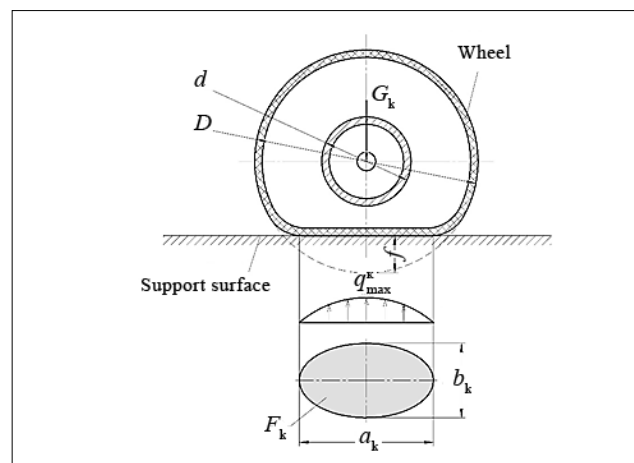$$P_{cr} = G_k^o \cdot \varphi_c^o = G_k^A \cdot \varphi_c^A, \tag{3}$$

Fig. 2. Diagram of the wheel pneumatic tire deformation during static tests:

f – normal tire deflection, m; D – the outer diameter of the tire, m; d – rim landing diameter, m; b_k – the width of the contact patch, m; a_k – the length of the contact patch, m; F_k – contour contact area of the tire tread, m^2; q_{max}^{κ} – maximum normal pressure, kPa; G_k – static vertical load on the wheel, kN

Fig. 1. The maximum allowable pressure on the soil in the spring period of the main technological operations

11

СЕЛЬСКОХОЗЯЙСТВЕННЫЕ МАШИНЫ И ТЕХНОЛОГИИ • Том 14 • N3 • 2020   AGRICULTURAL MACHINERY AND TECHNOLOGIES • Volume 14 • N3 • 2020
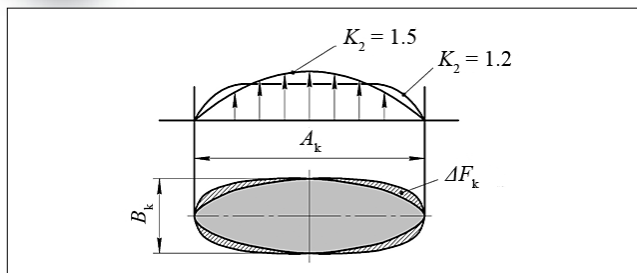
Fig. 3. The necessary increase in the area of the contact spot by 16% with a decrease in the coefficient of longitudinal irregularity: A_k – length of the contact, m; B_k – width of the contact patch, m; ΔF_k – increase in the area of the contact at $K_2 = 1.2$, m^2

Fig.4. Coordination of the maximum pressure q on the soil with permissible norms, coefficients of using the adhesion weight φ_c and the level of energy saturation E_{tr}

where $G_к^o$ – tractor on ordinary tires adhesion weight,
$G_к^A$ – tractor on agrophilic tires adhesion weight.
Based on the fact that $G_к^o = 36$ kN (Belarus 1020):

$$G_к^A = (G_к^o \cdot \varphi_c^o)/\varphi_c^A = (36 \cdot 0.39)/0.5 = 28 \text{ kN}.$$

Based on formula (1), the authors defined:

$$q^o/q_{max}^A = (K_2^o \cdot G_к^o \cdot F_к^o)/(K_2^A \cdot G_к^A \cdot F_к^A).$$

Where, taking into account the requirements for reducing the maximum pressure on the soil (*Fig. 1*) they got:

$$q_{max}^o/q_{max}^A = 150 \text{ kPa} / 80 \text{ kPa} = 1.88.$$

Given K_2^o, K_2^A, $G_к^o$, $G_к^A$ they determined:

$$1,88 = (1.5 \cdot 36 \cdot F_к^A)/(1.2 \cdot 28 \cdot F_к^o),$$

where $F_к^A = 1,16 \cdot F_к^o$,
where O – ordinary, A – agrophilic.

The scale of the increase in $F_к^A$ in comparison with $F_к^o$ was schematically shown in (*Fig. 3*), and the sequence of actions to reduce the maximum pressure on the soil was shown on the nomogram (*Fig. 4*).

The nomogram graphically shows a decrease in the maximum pressure q on the soil from 150 kPa to 80 kPa ($\Delta\Sigma$) with an increase in the adhesion weight use factor φ_c from 0.39 to 0.50 due to a decrease in the adhesion weight from 36 kN to 28 kN, a decrease in the coefficient of longitudinal irregularity of K_2 from 1.5 to 1.2 – ΔK, an increase in the tire contact area by 16% – ΔF with a constant traction force $P_{cr} = 14$ kN and an increase in the energy saturation of E_{tr} from 2,0 kW/kN to 2,6 kW/kN, corre-
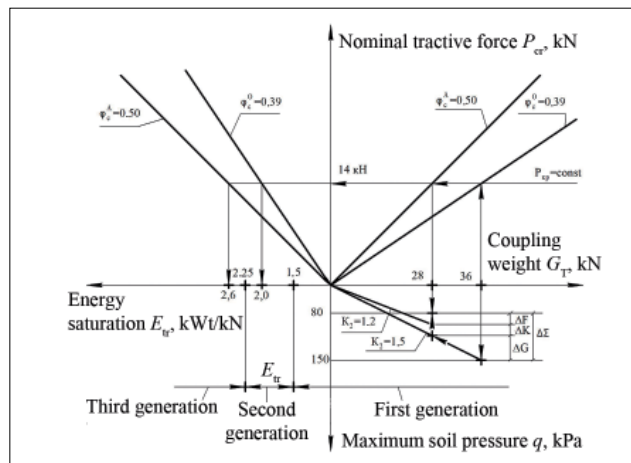
sponding to Professor G.M. Kutkov qualifications for third-generation tractors.

Summarizing the results of the research presented in *tables 2*, *3*, as well as in *figure 5*, it was necessary to include in the revised State Standard 27021-86 "Agricultural and forestry tractors. Traction classes ", the following recommendations.

The nominal tractor tractive force in kilonewtons was determined by the formula

$$P_{cr.nom} = A \cdot m_e,$$

where A – coefficient set depending on the tractor type;
m_e – operating weight of the tractor, kg.

Coefficient A take equal:
$3.24 \cdot 10^{-3}$ – for agricultural tractors:
$3.73 \cdot 10^{-3}$ – for tractors with an operating weight of up to 2600 kg;
for four- and three-wheeled tractors with two driving wheels (4K2 and 3K2) with an operating weight of over 2600 kg;
for four-wheel tractors with four driving wheels (4K4) and an operating weight of over 2600 kg:
$3.92 \cdot 10^{-3}$ – with tires of the ordinary concept;
$5.00 \cdot 10^{-3}$ – with ultra-low pressure tires;
for tracked tractors:

Таблица 2						Table 2
THE MAIN INDICATORS OF THE TRACTION CHARACTERISTICS OF THE CATERPILLAR TRACTOR T-250						
Soil background	Winter wheat stubble					
Operational weight, kg	13200					
Transmission	1-3	1-4	II-1	II-2	II-3	II-4
Maximum traction power, kW	151.7	149.0	148.94	147.95	147.25	142,5
Traction force, kN	97.5	87.0	75.0	61.0	51.0	47,5
Speed, km/h	3.6	6.2	7.15	7.95	9.3	7,8
Slipping, %	6.2	2.9	1.7	1.5	1.2	0,9
Conditional traction efficiency	0.809	0.799	0.794	0.789	0.785	0,760
Coupling weight utilization rate	0.74	0.66	0.57	0.46	0.39	0,36

12

СЕЛЬСКОХОЗЯЙСТВЕННЫЕ МАШИНЫ И ТЕХНОЛОГИИ • Том 14 • N3 • 2020   AGRICULTURAL MACHINERY AND TECHNOLOGIES • Volume 14 • N3 • 2020

EXISTING AND RECOMMENDED CHARACTERISTICS OF RUNNING SYSTEMS

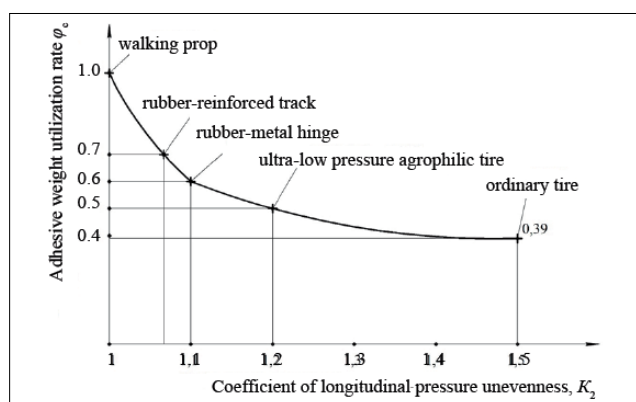| Indicators	Traction concept (GOST 27021-86)		Agrophilic concept (GOST 26955-86)		
	Wheel scheme 4K4a	Track scheme	Ultra low pressure tire wheel	Track	
				rubber-reinforced track with combined friction-pinned engagement RAG*	metal with rubber-metal hinge and torsion bar suspension of road wheels RMSh**
Adhesive weight utilization rate	0.39	0.49	0.50	0.70	0.60
Allowable slipping, no more,%	16	5	3	3	3
Maximum pressure on the soil, kPa	150.0	110.0	80.0	80.0	80.0
Permissible maximum pressure, kPa	80.0				
* RAG – *rubber-reinforced track* ** RMSh – *rubber-metal hinge*					

Fig. 5. Generalized hypothetical (assumed) dependence of the adhesive weight utilization rate φ_c on the longitudinal unevenness coefficient

$4.9 \cdot 10^{-3}$ – with a caterpillar of the ordinary concept;

$6.0 \cdot 10^{-3}$ – with rubber-metal hinge track, rollers with torsion bar suspension;

$7.0 \cdot 10^{-3}$ – rubber-reinforced track with a combined friction-pinching system of force transmission

for forestry tractors:

$4.4 \cdot 10^{-3}$ – for tracked tractors;

$3.4 \cdot 10^{-3}$ – for wheeled tractors.

In the absence of data to determine the operating mass, it was taken equal to:

1.15 – values of structural mass for wheeled tractors;

1.08 – values of constructional mass for tracks.

CONCLUSIONS. Taking into account the research data as an agrophilic direction, ensuring compliance with the norms of impact on the soil, and positively solving the problems of energy saturation, it was possible to recommend the development of running systems to ensure the achievement of the adhesion weight use factor $\varphi_c = 0.5$ (ultra-low pressure tire), $\varphi_c = 0.6$ (rubber-metal hinge with torsion bar suspension) and $\varphi_c = 0.7$ (rubber-reinforced track).

The conducted research, taking into account the available data on traction tests of the T-250 tracked tractor, would make it possible to include the agrophilic concept with a hypothetical (assumed) dependence of the adhesion weight use factor φ_c on the longitudinal unevenness coefficient K_2 in the form of recommendations in the revised State Standard 27021-86 "Agricultural and forestry tractors. Traction classes "[15-20].

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13

СЕЛЬСКОХОЗЯЙСТВЕННЫЕ МАШИНЫ И ТЕХНОЛОГИИ • Том 14 • N3 • 2020   AGRICULTURAL MACHINERY AND TECHNOLOGIES • Volume 14 • N3 • 2020

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14

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