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EVALUATION OF METHODS FOR EXPERIMENTAL AND ANALYTICAL DETERMINATION OF THE CONTOUR AREA OF THE CONTACT PATCH OF A PNEUMATIC TIRE WITH A SUPPORT BASE

A.V. LIPKAN'[1]
A.N. PANASYUK[1], Dsc in Engineering
Z.A. GODZHAYEV[2], Dsc in Engineering
A.V. LAVROV[2], PhD in Engineering
A.V. RUSANOV[2]
V.A. KAZAKOVA[2]

[1] Far Eastern Research Institute of Agricultural Mechanization and Electrification, Blagoveshchensk, Russia, lav-blg@mail.ru
[2] Federal Scientific Agroengineering Center VIM, Moscow, Russia, fic51@mail.ru

The results of experiments on the estimation of the error of methods of experimental and calculated determination of the contour area for the ecological assessment of a mobile energy device are presented. There was used the example of modern radial tires 360/70R24 of Bel-89 and 18.4R34 of F-11 agricultural tractor MTZ-1025.2. in modes of non-nominal loading at nominal load on tires and changes in tire pressure within the range recommended for field work. assess the possibility of improving the computational method for determining the contour area of the contact patch of the tire tread of a pneumatic wheel based on the mathematical model of V.L. Biederman. The assessment was carried out for four ways of determining the area of the tire contact patch: 1) directly measuring the area using a digital photograph of the tire contact patch in Kompas-3D V13 software with the determination of the scaling and method error using a square from 100x100 mm graph paper; 2) calculation by the formula of the area of an ellipse, using the length and width of the tire contact patch, measured with a tape measure directly from the obtained print; 3) by calculation, determined from the digital photograph in Kompas-3D V13 software; 4) by calculation, determined by calculation using the parameters of the universal tire characteristic (UTC).
As a result of the experiments, it was found that for modern radial tractor tires, the static deformation of which does not exceed 18–22 %, the method of theoretical determination of the contour area of the tire contact patch using the UTC parameters can be applied with sufficient (for engineering practice) accuracy. Full convergence of the calculated and experimental contour areas of the tire contact patch can be provided by the coefficient of their ratio. The carried out assessment of the possibility of using methods for calculating the conditional contour area of the tire showed that these methods can be well used for a comparative assessment of the technogenic mechanical impact of propellers on the soil.

Keywords: propeller, deformation, characteristic, method, contour area, support base, maximum pressure.

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Introduction

In the Russian Federation, the determination of the impact of wheeled propellers of agricultural machinery on the soil is based on two standardized criteria to resolve the environmental assessment issue of a mobile energy device (MED).

• GOST R 58656-2019 [1] officially indicates that the maximum normal pressure of a single wheel on the soil $q^{к}_{\max}$ (kPa) is calculated on the basis of the experimentally determined average $\overline{q}_{к}$ (kPa):

$$\overline{q}_{к} = \frac{G_{к}}{F_{кп}}; \qquad (1, a)$$

$$q^{к}_{\max} = \overline{q}_{к} \cdot K_2 = \frac{G_{к}}{F_{кп}} \cdot K_2 = \frac{G_{к} \cdot K_2}{F_{к} \cdot K_1}, \quad (1, б)$$

where G_w is the radial (vertical) load on the wheel, kN; F_{CA} is the contact area of the tire of a single wheel, which is reduced to working conditions on a soil base; F_C is the contour area of the contact patch of the tire tread with a rigid support base; K_1 is the coefficient based on the outer diameter of the wheel tire, which is taken in accordance with GOST R 58656 [1]; K_2 is the coefficient of longitudinal non-uniformity of pressure distribution over the contact area of the tire, K_2 = 1.5.

• [2] proposed that the impact indicator of a single-wheeled propeller on the soil U (kN/m) is calculated using the value $q^{\kappa}_{\max}$:

$$U = \omega b q^{\kappa}_{\max}, \quad (2)$$

where ω is a coefficient that depends on the size and bearing surface of the propeller. The authors of [2] experimentally determined ω to be 1.25 for a wheeled propeller, and b is the propeller width.

The analysis performed by the authors of [2] showed that the impact indicator of a single propeller U, which is determined by dependence under Eq. (2), meets the requirements for the numerical parameters of the "propeller–soil" system. Thus, this indicator can be used as an adequate criterion for assessing the compaction effect of propellers on the ground.

Nevertheless, the calculation of both criteria is based on the determination of the contour contact area F_C of the tire tread with a rigid support base with one difference: the F_C in the first case is determined by the experimental tire contact patch obtained in accordance with GOST R 58656-2019 [1], while that in the second case is identified by calculation using the parameters c_1, c_2, and p_0 of the universal tire characteristic (UTC) based on the mathematical model of V.L. Biderman, which describes the radial deformation process of tractor tires, thus demonstrating the following equation [2, p. 205]:

$$G_{\kappa} = \frac{f^2_{\text{ш}}}{c_1 + c_2 \cdot f_{\text{ш}} / \left(p_{\text{w}} + p_0\right)}, \quad (3)$$

where $c_1(\frac{м^2}{кН})$, c_2 $(\frac{1}{м})$ and p_0 (kPa) are constant coefficients for a given tire, and the primary (controllable) operational parameters characterizing its loading are p_w (kPa) and G_w (kN) as internal tire pressure and radial (vertical) load on the tire, respectively.

The combination of UTC and primary operational parameters according to the method stated in [2, p. 205–207] determines the secondary (dependent) performance parameters of the tire as normal static tire deflection f_T, linear parameters of the contact patch (width b_C and length a_C), and the conditional contour area of the contact patch of the tire tread on a flat, non-deformable support base F_C based on the tire diameter D_0 (m) and the area reduced to working conditions on a soil base F_{CA}. In combination with the radial load on the tire G_w, the aforementioned approach determines the average $\overline{q}_{\text{к}}$ and the maximum normal pressure on the soil $q^{\kappa}_{\max}$ as well as the indicator of the tire impact on the soil as a single wheel propeller U (kN/m).

The values of the coefficients c_1, c_2, and p_0 for a particular tire are determined in accordance with the results of its static tests, for which three experiments are sufficient. These tests are performed in at least two different internal air pressures in the tire or determined for all tractor tires without exception from the dependencies proposed by M.I. Lasko and A.G. Kurdenkov [2, p. 206] according to data i = 3, ..., N steps of combinations of radial (vertical) load on the tire G_{wi} and internal tire pressure p_{wi}, providing its admissible static deflection $[f_T]$; that is, the values are determined in accordance with the load characteristics of the tire during its static tests by the manufacturer [4–12].

However, each of these methods currently has its drawbacks. Thus, the experimental method for determining the contour area of the tire tread contact patch on a flat, rigid support base F_C accordance to GOST R 58656-2019 [1] is laborious and organizationally difficult because it involves the use of a special stand or manipulation with full-scale samples of mobile machines. In addition, considering regulating the method of obtaining a tire tread footprint, GOST R 58656-2019 [1] does not provide a clear guideline of the *method for assessing the value of the area* of this footprint.

The disadvantage of the second method for radial tires lies in the uncertainty of the coefficient p_0 when calculating the normal deflection f_T because the tire design parameter "ply rate n" used in this case is not indicated by their manufacturers in the specification for most modern radial tires. This phenomenon complicates the possibility of using this method because it induces a particular uncertainty in the adequacy of the calculations.

Therefore, investigating highly elastic radial tires IF and VF with a relative radial deformation significantly more than 18 %–22 %, A.Yu. Rebrov [13] proposed to adapt the method for calculating the contour area of contact of a tire tread with a rigid supporting surface based on the mathematical model of tractor tire deformation by V.L. Biderman. This model uses the equality of the calculated and actual contour area of the tire contact patch with a rigid base as a criterion for the convergence of the simulation results and real data. He developed a method for identifying the calculated value of the contour area of the tire tread contact patch with a rigid support base. He also introduced the design parameter "ply rating *n*," which is the conventional value n_c that characterizes the stiffness of the tire carcass, and the identification coefficient k_F of the calculated value of the contour area to its actual value, in which nominal value is given (e.g., by well-known manufacturers of international tires).

A.Yu. Rebrov [13] indicated that in the calculations according to the method described in [2], the ply rating *n* for the model with an unspecified value of this parameter is initially chosen in such a way to exclude complex values in the calculations using dependence under Eq. (3). After determining the contour area of the contact patch of the tire with a rigid base F_{cc} in accordance with the basic method (Eqs. (5.25)–(5.28) in [2]), the coefficient is determined as follows:

$$k_F = \frac{F_{\text{кр}}}{F_{\text{кн}}}, \tag{4}$$

where F_{cc} is the calculated contour area of the tire contact patch, and F_{nc} is the nominal contour area of the tire contact patch according to the test data of the manufacturer.

The dependences of the reduced radius and coefficient c_3 are then respectively adjusted as follows:

$$R_{\text{пр}} = \frac{B+H}{2{,}5 \cdot k_F}, \tag{5}$$

$$c_3 = \frac{\dfrac{20{,}5}{\sqrt{k_{\text{F}}}}}{11{,}9 + \left| \dfrac{D}{B} - \dfrac{|n_c - 9|}{2} - 3 \right|}. \tag{6}$$

Furthermore, the ply rating n_c is determined numerically from the following equation below after respectively replacing equations in R_{pr} and c_3 by the modernized Eqs. (5) and (6).

$$\frac{F_{\text{кр}}}{10000} = \frac{\pi}{2} \cdot \frac{\dfrac{20{,}5}{\sqrt{k_{\text{F}}}}}{11{,}9 + \left| \dfrac{D}{B} - \dfrac{|n_c - 9|}{2} - 3 \right|} \times$$

$$\times \sqrt{D \cdot f_{\text{ш}} - f_{\text{ш}}^2} \cdot \sqrt{2 \cdot \frac{B+H}{2{,}5 \cdot k_F} \cdot f_{\text{ш}} - f_{\text{ш}}^2} \tag{7}$$

where f_T is the static deflection of the tire.

Notably, A.Yu. Rebrov [13] indicated that the ply rating n_c is a conditional index and can take any (not necessarily integer) values. The values of the nominal contour area of the contact patch for the same tire size with remarkably similar dimensions can differ by up to 40 % [13]. The contour area of the contact patch of IF and VF tires is occasionally smaller than that of conventional radial tires of the same size. Therefore, referring to the data of the manufacturer and performing identification is necessary in each specific case. The identified values of the coefficient k_F show that the calculated contour area of the contact patch may differ from the actual one to the high and low sides before the dependency correction of Eqs. (5) and (6). Thus, the method for identifying agricultural tractor tires of categories IF and VF, which is proposed by A.Yu. Rebrov using the well-known mathematical model of V.L. Biderman [2] constructed on the universal characteristic of tires, helps determine the coefficients k_F, c_3, and n_c of the tire model from the equality condition of the calculated and actual contour areas of the tire contact patch with a rigid support base $F_{cc} = F_{nc}$.

The proposed method for identifying radial tires based on traditional technology as well as tires of categories IF and VF is highly accurate. The difference between the calculated and actual contour areas of the contact patch with a rigid base at a *nominal* load is ±2 cm² [13].

Notably, the proposed method by A.Yu. Rebrov is correct considering the nominal loading modes of the tire, which correspond to the load characteristic points recommended by the manufacturers according to the condition of the admissible static deflection of the tire; that is, provided that the area in this case is also a constant value, which is defined as the "nominal contour area" of the tire tread contact with a rigid support basis. Will such an approach be appropriate if calculating the contour area of the tire tread contact patch with a rigid support base is necessary (e.g., in the "tire underload" mode)? That is, if the nominal load at the set tire pressure is less than the recommended one, then whether the pressure under this tire meets the environmental requirements for impact on the soil should be assessed. Otherwise, the tire pressure should be reduced but not lower than the level of ensuring the permissible static deflection and the nominal contour area of the tire tread contact patch accordingly. Assessing the nature and absolute value of the contour area of the tire tread contact patch from a change in the intra-tire pressure in a given range with a constant nominal load on the MED wheel is occasionally necessary to improve the supporting and/or traction-coupling properties of a pneumatic wheel propeller. The possibility of utilizing the analytical calculation method on the tire contact area based on the use of UTC parameters remains unknown.

The V.L. Biderman model (UTC parameters) is used at a non-rated loading mode (e.g., when the tire is "underloaded") in the initial absence of such data from the tire manufacturer as the "ply rating *n*" index and the actual value of the nominal contour area of the tire tread contact patch, which may be a criterion for the possibility of using the proposed approach for correcting the calculation method to determine the contour area of the tire tread contact patch with a flat rigid surface.". Such criteria can include the following: the identity of the calculated and actual characteristics of the intra-tire air pressure influence on the change in the contour area and the magnitude of the error in its determination.

Specifically, the error of possible methods for assessing the obtained contour area value of the tire tread contact patch using the recommended experimental method according to GOST 7057-2001 [3] should be estimated in the course of experimental studies. This estimation aims to verify the possibility of utilizing the computational method to determine the contour area value of a radial tire using a mathematical model of V.L. Biderman in a non-rated loading mode with a standard load, which is accompanied by a change in the intra-tire pressure in the recommended range for fieldwork and the conditional value of the "ply rating *n*" parameter. As mentioned above, the assessment method of the contour area value of the tire tread contact patch is currently controlled by the regulatory documents of the Russian Federation. Therefore, this method can either be an instrumental way of directly or indirectly (e.g., using a digital camera) measuring the contact patch area or a process of calculating the contact patch according to its measured parameters by the instrumental approach directly or indirectly using a digital camera, namely the length a_c and the width b_c.

Study aim

1. Evaluate the possibility of using the computational method for determining the contour area of the tire tread contact patch of a pneumatic wheel based on the mathematical model of V.L. Biderman. That is, the UTC parameters are used to assess the actual contour area values of the tire tread contact patch with a rigid support base, the maximum pressure, and the impact index of a single-wheeled tractor propeller on the soil in the modes of non-nominal tire loading when the intra-tire pressure changes in the recommended range.

2. Experimentally and theoretically determine the effect of intra-tire air pressure on the contour area of the radial tire tread contact patch with a rigid support base by using UTC parameters at a standard load on the wheel.

3. Estimate the errors in determining the contour area of the radial tire tread contact patch on a rigid support base by using experimental and computational methods, including the use of UTC parameters.

Research objects

Tractor MTZ-1025.2:

- Front left wheel (FLW) tire 360/70R24 "Bel-89" TU 6700016217.178-2003 12.2-18 "Belshina" 2.5 bar marks 106R 000032;
- Rear right wheel (RRW) tire 18.4R34 mod. F-11 GOST 7463 "Belshina" 2.5 bar maks 106R 000045.

Laboratory experiments were performed to address problem 1 by obtaining a footprint of tires on a flat support base using the method according to GOST 7057 [3] without dismantling tires from the tractor, which is comprehensively described in [14].

Materials and methods

The contour area size of the resulting tire contact patch at a given value of the intra-tire pressure was determined by the following four methods.

1) Indirect measurement using a digital photograph of the tire contact patch footprint in the "Kompas-3D" V13 software environment and its "Measure area" tool with the definition of scaling using a square from a 100 × 100 mm graph paper;

2) Area calculation of an ellipse [2, Eq. (5.28)] using the length a_{c1} and the width b_{c1} of the tire contact patch, which is computed with a measuring tape directly from the obtained footprint;

3) Area calculation of an ellipse using the length a_{c2} and width b_{c2} of the tire contact patch footprint, which is determined from its digital photograph in the "Kompas-3D" V13 software environment using its "Measure distance" tool, and identification of the scaling using a square from a 100 × 100 mm graph paper;

4) Calculation employing the area equation of an ellipse using the length a_{c3} and the width b_{c3} of the tire contact patch, which is determined by the computation utilizing the UTC parameters [2, Eq. (5.27)] at the conditional ply rate of the tire $n = 8$.

The error in determining the area through the aforementioned methods is estimated as follows.

• Method 1 of indirect measurement of the area indicates the relative error in determining the area of a square from a 100 × 100 mm graph paper (that is, the known area of 10,000 mm^2) using the tool "Measure area" of the "Kompas-3D" V13 program;

• Calculation methods 2, 3, and 4 for determining the contour area of the contact patch, wherein the relative error considering the contour area value determined by measuring method 1 is taken as the basic one and the most accurate in reflecting the actual contour area of the tire contact patch.

Results and discussion

The results of various measurement and determination methods by calculating the area of footprints with an estimate of the comparative determination error considering the basic (main) method are summarized in Table 1. Figure 1 presents the graphs of area dependence of the tire tread contact patch for the front (FLW) and rear (RRW) axles of the MTZ-1025.2 tractor on the intra-tire air pressure, as determined by the four aforementioned methods.

The contour area values of the tire tread contact patch, which are evaluated on the basis of the intra-tire air pressure and determined using four different ways, are presented in Table 1. Lines 1 and 2 (italicized), which respectively correspond to a certain pressure in the tire and the error in determining F_c using the aforementioned methods, is presented considering the basic method 1 (the conditional error of determination is equal to zero) of its indirect determination using a computer program.

Table

Change in the area of the tire tread contact patch from the intra-tire air pressure for the front (FLW with tire 360/70R24) and rear (RRW with tire 18.4R34) of MTZ-1025.2 tractor axles, determined by various methods with an estimate of the determination error relative to the basic method

Intra-tire air pressure	Measurement of area in "Kompas", mm^2		Calculation of the area according to the actual linear dimensions, mm^2		Calculation of the area according to the linear dimensions of the footprint in "Kompas," mm^2		Calculation of the area according to the linear dimensions determined in accordance with UTC, mm^2	$\frac{F_{к4}}{F_{к1}}$	$\frac{F_{к2}}{F_{к1}}$
p_w, kPa	$F_{к1}$	F_{1001}	$F_{к2}$	F_{1002}	$F_{к3}$	F_{1003}	$F_{к4}$, $n = 8$	k_F	k_F
1	2	3	4	5	6	7	8	9	10
FLW–360/70R24 "Bel-89" TU 6700016217.178-2003 12.2-18 "Belshina" 2.5 bar maks 106R 000032								k_{F1}	k_{F2}
80	82222,0	10111,4	75900,9	10000	76469,9	10056,0	75273	0,92	0,92
	0	*1,11*	*–7,69*	*0*	*–7,00*	*0,56*	*–8,45*		
135	65301,3	10003,8	61323,9	10000	62692,2	10011,0	67526	1,03	0,94
	0	*0,04*	*–6,09*	*0*	*–4,00*	*0,11*	*3,41*		
155	60710,7	10000,3	58480,7	10000	58226,0	10048,1	65980	1,09	0,96
	0	*0,003*	*–3,67*	*0*	*–4,09*	*0,48*	*8,68*		
RRW 18.4R34 mod. F-11 GOST 7463 "Belshina" 2.5 bar maks 106R 000045								k_{F3}	k_{F4}
80	169925,8	10030,7	160221,2	10000	159594,5	9998,0	150081	0,88	0,94
	0	*0,31*	*–5,71*	*0*	*–6,08*	*–0,002*	*–11,68*		
110	142534,5	10042,6	135842,5	10000	139677,1	10023,0	138833	0,97	0,95
	0	*0,43*	*–4,70*	*0*	*–2,00*	*0,230*	*–2,60*		
145	114878,6	10019,9	111797,5	10000	113057,9	9926,1	130762	1,14	0,97
	0	*0,20*	*–2,68*	*0*	*–1,58*	*–0,740*	*13,83*		

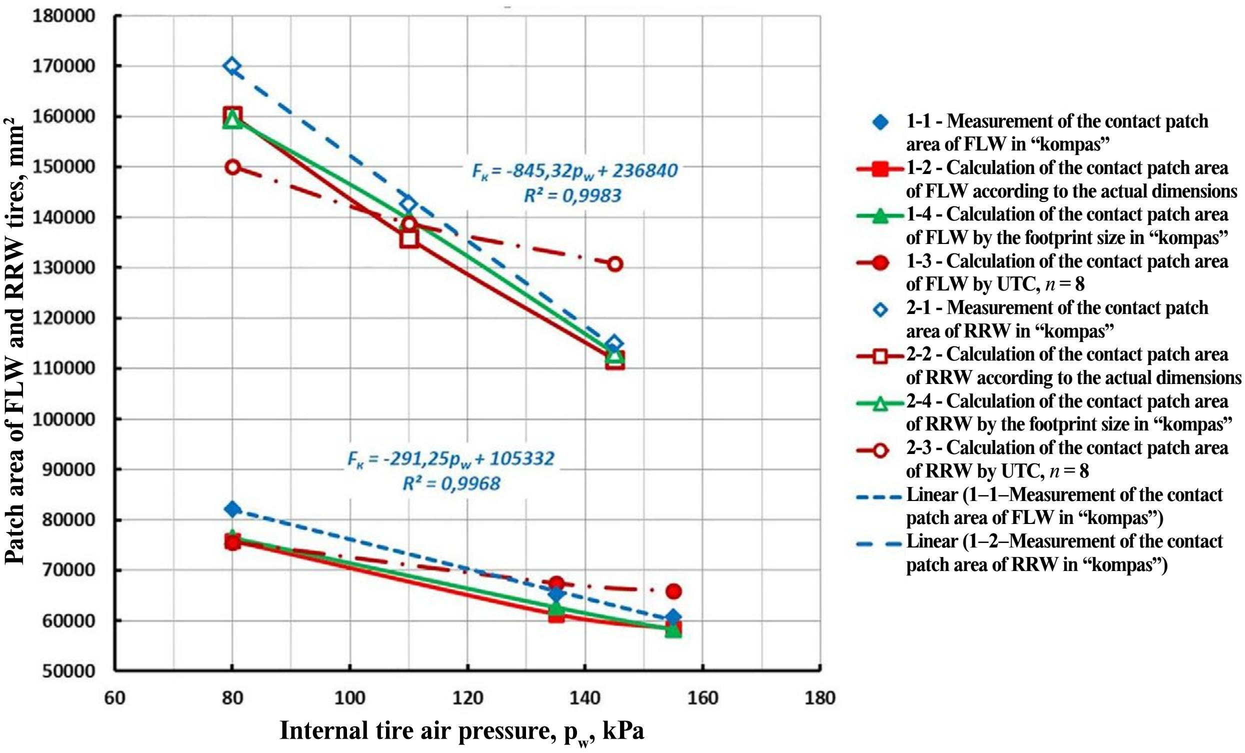

Fig. 1. Changing the contour area of the contact patch of the tires of the front (FLW with tire 360/70R24) and rear (RRW with tire 18.4R34) axles of the MTZ-1025.2 tractor on a rigid support base, defined in 4 ways

Fig. 1 shows that the nature of the contour area dependence is inverse and close to linear: that is, the value of the contour contact area decreases with an increase in the intra-tire pressure; this value tends to stabilize for the tire 360/70R24. Nevertheless, the value can be approximated by a linear dependence for both tires over the entire investigated pressure range, as evidenced by the high value of the coefficient of determination R^2 = 0.9968–0.9983 trend lines (interrupted lines) of dependence according to the basic method of determining F_{c1}.

The contour area size of the contact patch increases by 35.43 % and 47.92 % respectively for the front and rear axle tires with a decrease in pressure from 155 and 145 kPa to 80 kPa, which accordingly determines the decrease in the maximum normal pressure on the soil. The main method for determining the contour area of a footprint in the "Kompas" program (column 3) and the calculation method for identifying the contour area of a footprint by its linear dimensions (determined in "Kompas" (column 7)) are characterized by approximately the same low determination error using these methods. The area of a 100 × 100 mm square, which is fixed in the center of the footprint when photographing (columns 3 and 7), is relative to the square area determined by the calculation according to its actual dimensions (column 5). The error in determining the area using these methods does not exceed 1.5 % of the level regulated by GOST 7057-2001 [3].

A significantly large error in the calculation methods for determining the contour area of the footprint (columns 4, 6, and 8) considering the indirect measuring method (column 2), which is taken as the basic one and most characterized by the accuracy of determining the area of a 100 × 100 mm square by this method (column 3), is mainly related to certain inadequacies in identifying the actual shape of the footprint and that of an ellipse. In this case, the error (columns 4 and 6) reaches 7.69 % downward for the tire *360/70R24*, while that for the tire *18.4R34* is equal to 6.08 %.

Calculations of the footprint area according to method 4 using the UTC parameters and the error of its determination considering the main method (column 8) were performed for these tires at a conventionally accepted ply rating n = 8, thus revealing a slightly large error. Moreover, at the beginning of the investigated range of intra-tire air pressure, the values of the contour contact area of the tire *360/70R24* according to method 4 decreased by −8.45 %, while those at the end of the range are almost symmetrically increased (+8.68 %). By contrast, the reduction of the area F_{c4} for the *18.4R34* tire is –11.68 % at the beginning of the investigated air pressure range in the tire p_w, while that at the end of the range increases by +13.83 %. In the middle of the range, the error in determining the contact area using method 4 does not exceed +3.41 % and –2.60 % of the tires *360/70R24* and *18.4R34*, respectively.

Columns 9 and 10 of Table 1 show the identification coefficient calculated using methods 2 and 4 for determining the contour area of the contact patch. The table reveals that in the case of "underload," the coefficient k_F proposed by A.Yu. Rebrov is a variable value and can be approximated by a linear relationship (Fig. 2), as evidenced by the high value of the coefficient of determination R^2 = 0.862–0.998.

Conclusions

1. The actual and calculated change values of the tire tread contact patch from the intra-tire pressure based on the V.L. Biderman model are determined by an inverse linear relationship. Simultaneously, the contact area with the rigid support base can be increased by reducing the intra-tire pressure in tires from 155 and 145 kPa to 80 kPa at standard loads for the tested MTZ-1025.2 tractor. Accordingly, the maximum normal pressure $q^K_{\max}$ and the soil impact indicator U for the front wheels with *360/70R24* tires can be reduced by 35.43 %, while that for the rear axle wheels with *18.4R34* tires can be decreased by 47.92 %.

2. The easy method 4, that is, the calculation of the normal static deflection of the tire f_T, can be used due to its sufficient accuracy for engineering practice in determining the contour contact area of tires (consequently determining the maximum pressure on the soil $q^K_{\max}$ and the indicator of the impact on the soil of the wheel propeller U). Accordingly, the contour area of the tire contact patch with a rigid support base F_c with known UTC constants can also be obtained using the aforementioned method despite the conventionality of determining the ply rating n = 8 for modern radial tires *360/70R24* and *18.4R34* when the error does not exceed 8.7 % and 13.8 %, respectively.

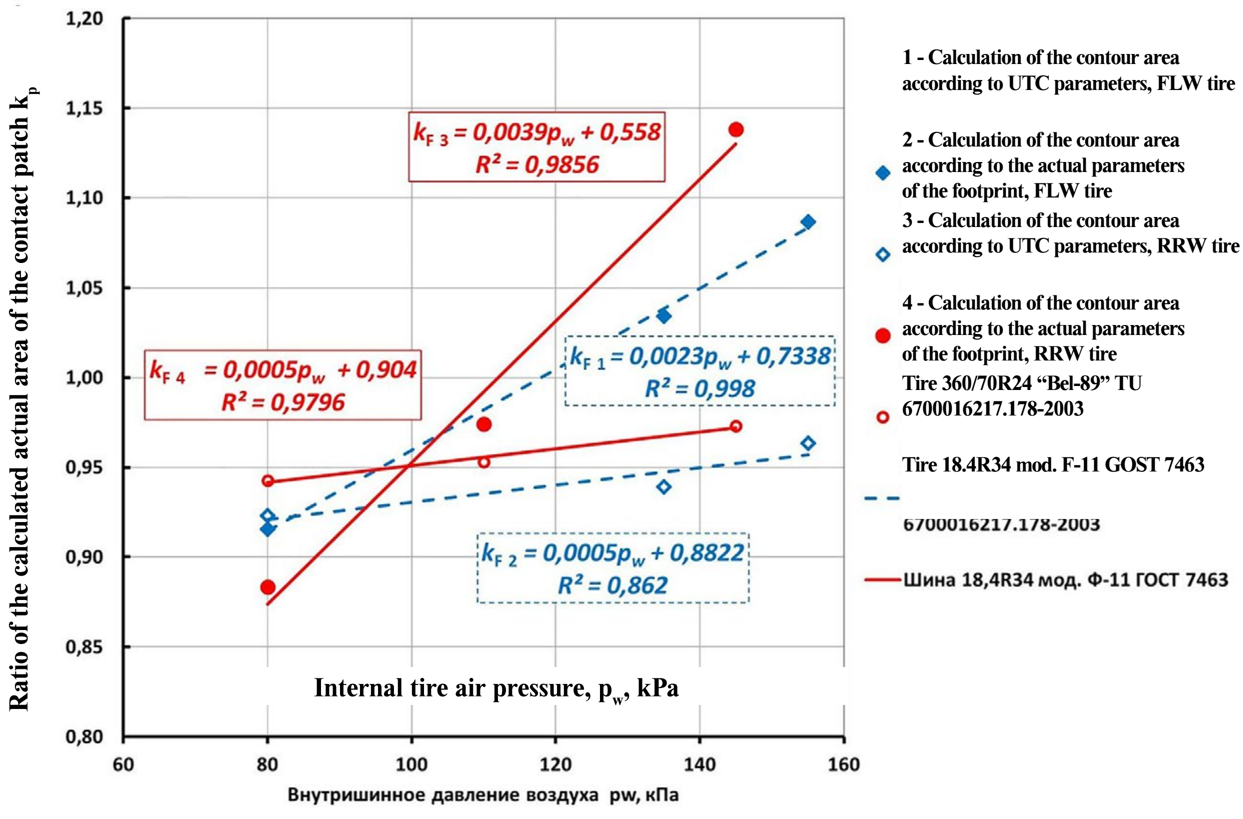

Fig. 2. Dependence of the identification coefficient k_F of the calculated method for assessing the contour area of the contact patch of the tire tread on a rigid support base on the tire pressure p_w at n = 8 for the nominal load on the axles of the MTZ-1025.2 tractor

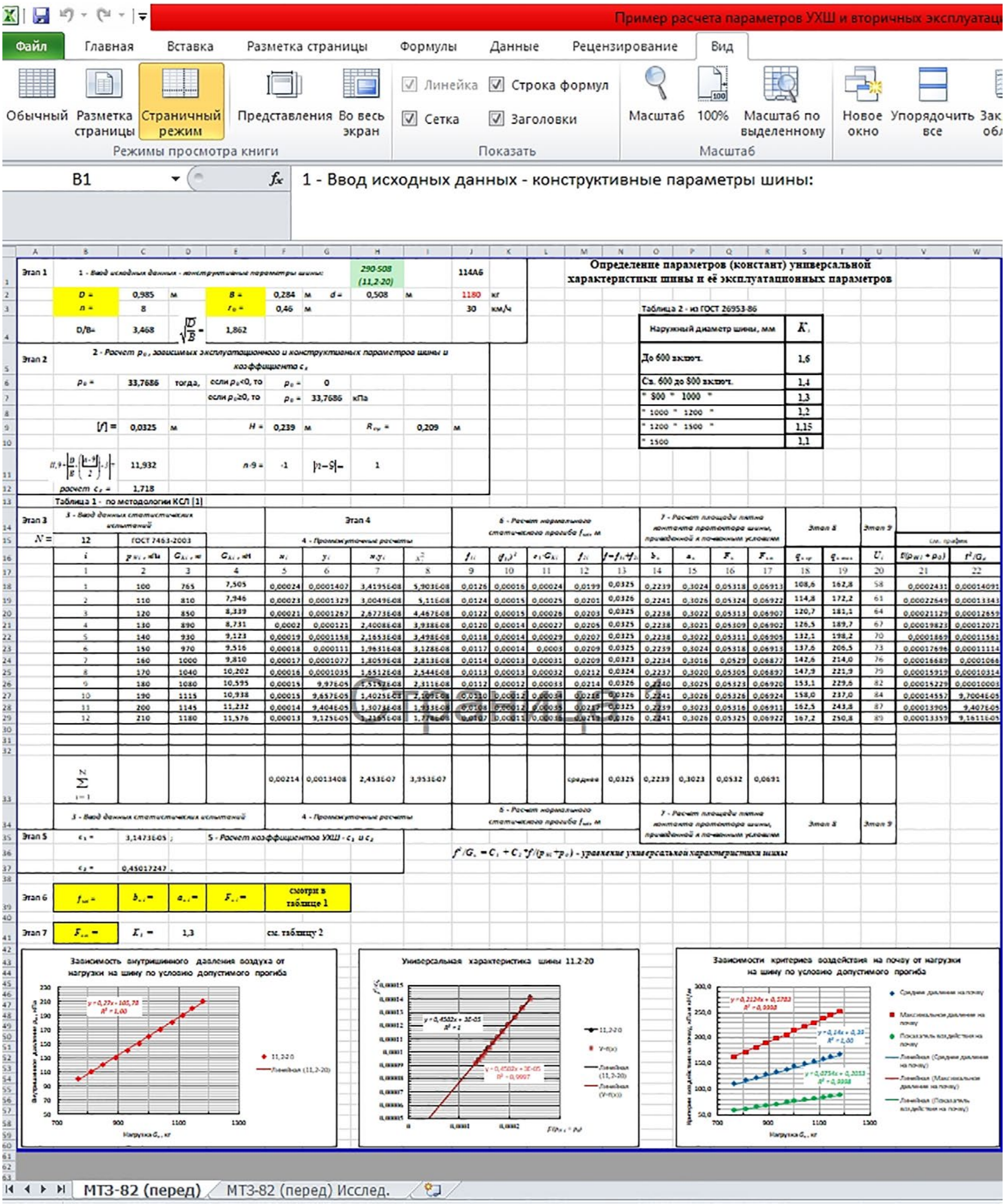

Fig. 3. An example of calculating the parameters of UTC and secondary operational parameters of a tire as a single wheel propeller

3. The methodological approach of A.Yu. Rebrov can be used for the complete identification of the contour area calculation data of the tread contact patch of modern tractor tires with their actual contour area on a rigid support base, thus minimizing the error in the theoretical determination of the impact level of pneumatic wheel propellers on the soil. This approach can be employed in nominal tire loading and the "underload" (at f_T < $[f_T]$) phenomenon, approximating in the latter case the identification coefficient of the accepted calculation method with a direct linear dependence.

4. The assessment of the possibility of using the method for calculating the conditional contour area of the tire using the UTC parameters revealed that such a method can be employed for comparative assessments of the technogenic mechanical impact on the soil through the evaluation of values of the maximum normal pressure $q^K_{\max}$ (kPa) and the indicator of the soil impact on a single wheel propeller U_i (kN/m). This method overestimates the inverse dependence on the contact area of the tire tread with the support base and the lower values of the recommended air pressure in the tire and underestimates the upper values of the recommended air pressure range, which does not exceed by more than 8 %–14 %. This value is quite acceptable for engineering calculations because it provides the research engineer with a method of determining the contour contact area of the tire tread for any (not only nominal) modes of combinations of radial (vertical) load on the tire G_w and air pressure p_w, corresponding to the admissible value of the static normal deflection of the tire $[f_T]$.

A program has been developed in the application package environment "Microsoft Excel" for calculating the contact patch area of a tire with a rigid support base based on the determination of the UTC and the secondary performance parameters of the tire considering a single wheel propeller. This calculation includes the indicators of impact on the soil $q^K_{\max}$ and U in nominal loading modes recommended by the tire manufacturer, that is, corresponding to the load characteristics. Methodological recommendations for the application of this program have also been presented [15], including a sample calculation for the tire 290–508 (11.2–20) and a sheet screenshot of "MTZ-82 (front)" of the program file spreadsheet. The universal characteristic of the tire – 2017. V.2 is presented in Fig. 3.

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