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## THE SUBSTANTIATION OF THE TENSE STATE OF SOIL UNDER CONDITION OF ITS INTERACTION WITH WHEELS

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*Machine and tractor devices which consist of large tractors and devices corresponding to them, are widely used in the fields. The use of such machine- and- tractor devices results in reduction of both energy usage and labor inputs. But the wheels of large tractors deform and consolidate the soil that results in changes of healthy soil structure as well as in worsening of the agro-ecological soil condition. The use of large machine- and tractor devices requires laying down of optimal constructional parameters for wheels. Optimized wheels will facilitate the decrease of both consolidation and devastation of the soil's fertile layer. The paper considers the interaction between the soil and the wheels. The scheme for determining the distribution of tension in soil under condition of vertical loading, has been developed. The task for the calculation of the tense state of soil has been formed. This task makes it possible to determine the level of tension in soil under the wheels of machine- and- tractor devices. The determination of the level of tension in soil enables to determine and to substantiate the parameters of the wheel tires. The use of such tires will make it possible to provide the level of normal state of tension in soil lower than a permissible level. As follows from solving a reverse contact problem, and under condition of equal distribution of contact pressure, a mathematic model has been received. The received mathematic model makes it possible to perform a computer simulation of the effects of wheels' width of the machine-and-tractor devices on tension which takes place in soil. The received model is universal and makes it possible to carry out the study of wheels of various standard sizes. A theoretical simulation of the performance of a machine-and-tractor device has been made. The distribution of tension in soil environment is given.*

**Keywords:** wheels, machine-and-tractor device, normal tension, tangent tension, soil structure.

### Introduction

Large tractors are used in the fields. The use of such tractors makes it possible to raise productivity and reduce energy consumption, but they have a significant impact on natural environment. Currently, an experience on reducing the harmful effects of such machines on the environment at the cost of using biofuel [1] has been in practice. Also, under the pressure of heavy tractors' wheels on soil, appears a tense state which depends on the rate and the distribution of the external load and causes deformation, and as a result, soil environment's over-consolidation. Soil over-consolidation results in decrease in crop yields [2; 3], destruction of its structure [4; 5] and other negative effects [6]. That is why, the reducing of harmful effect of heavy tractors on the environment requires setting optimal design parameters of wheels.

The study of wheels' contact with soil showed that it is rather difficult to find a tense state in soil. It depends not only on loads which effect the wheels, but also on tractor's driving speed and on the parameters of a pneumatic tire [7; 8]. Sliding of a tire is of great importance as well [9]. In such type

of study soil is treated as a tense and endless land which is limited by one horizontal surface [7; 10]. The soil environment is treated as homogeneous and isotropic one [8; 11]. But the results of the research obtained in above mentioned cases do not fully reflect the tense state of the soil environment. They will not help to determine the wheels' rational parameters either.

### Materials and methods

The study of the fields of tension in vertical soil profiles, under condition of soil tension made by wheels, was done using the methods of numerical service simulating tests by means of a specially developed computer program (fig. 1). This program made it possible to receive both the specifications of the distribution of the fields of tension and the numerical indexes of the rate of tension in separate, previously determined points of soil model on given scanning lines.

Further numerical modeling and service simulating test of a contact zone wheel-soil was performed on the algorithm, given on fig.2.

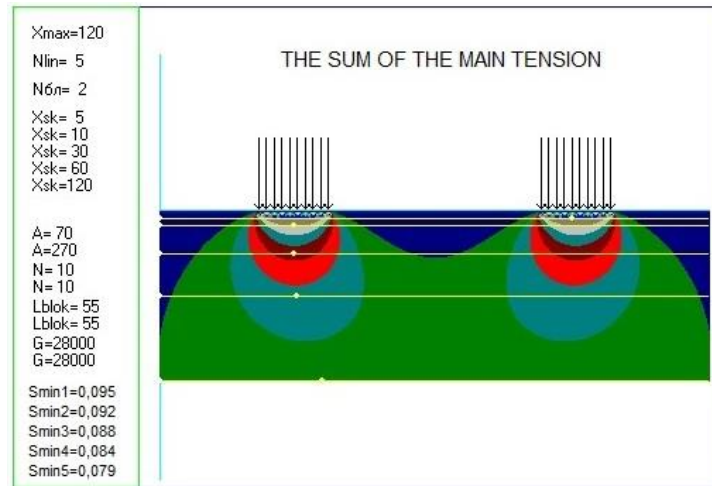


Fig. 1. Tension profile in a soil environment under tractor's wheels fitted with a sowing machine

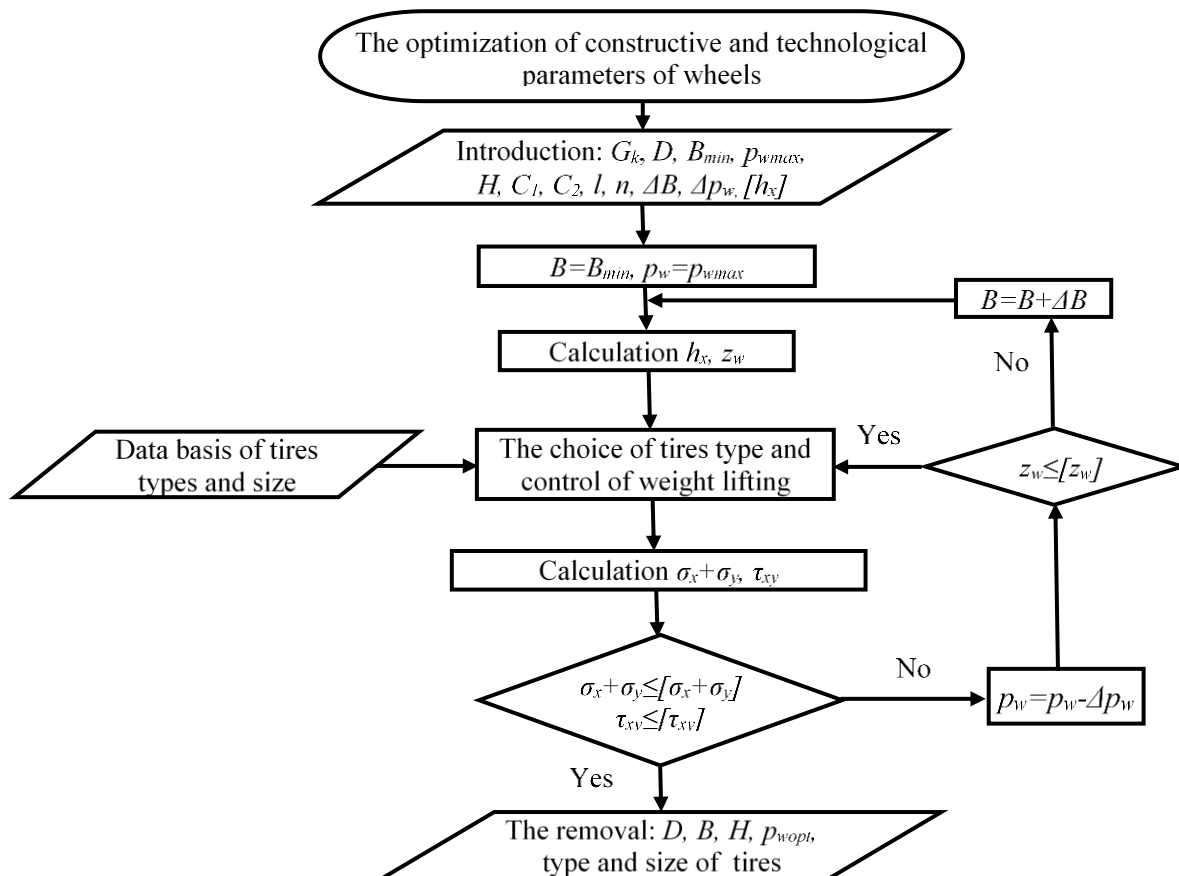


Fig. 2. Research algorithm and the optimization of constructive and operational parameters of wheels:

$G_k$  – is normal load on the wheel, H;  $D$  – is external diameter of a tire, m,  $B_{min}$  – is minimum permissible width of a tire section, m;  $p_{wmax}$  – is maximum permissible pressure in a tire, Pa;  $H$  – is height of a tire's section, m;  $C_1, C_2$  – is steel for a given type of a tire ( $C_1=0.0012\dots 0.0028\cdot 10^{-5} \text{ Pa}^{-1}$ ,  $C_2=0.25\dots 0.3 \text{ m}^{-1}$ );  $l$  – is distance between the wheels' extremities, m;  $n$  – is provisory amount of forces in a block of distributed tension;  $\Delta B$  – is spacing of width change of a tire's section, m;  $\Delta p_w$  – is spacing of pressure change in a tire, Pa;  $h_x$  – is normal deflection of a tire's dome, m;  $B$  – is real width of a tire section, m;  $\sigma_x+\sigma_y$  – is a sum of normal tensions, Pa;  $\tau_{xy}$  – is tangent tensions, Pa;  $z_w$  – is a relative ratio of deflection of a tire's dome;  $[z_w]$  – is a permissible deflection of a tire's dome

This program makes it possible to perform a computer simulation of the effects of MTA's wheels on the tension which appears in soil, as well as to choose their rational parameters.

### Results and discussion

A numerical solution of the task on determining the tense state of soil is possible under condition of using the iteration method. In the first approaching, soil is considered as elastic semi-space limited by horizontal surface. The accepted environment of a soil model is isotropic. Under these conditions was used the solution of Bussinesk's task. According to this method, the distribution of tense in a massive is symmetric about x axis. To develop a mathematic model of a tense state from a few blocks of distributed load, it was represented as a superposition n of forces exerted on corresponding points (fig. 3).

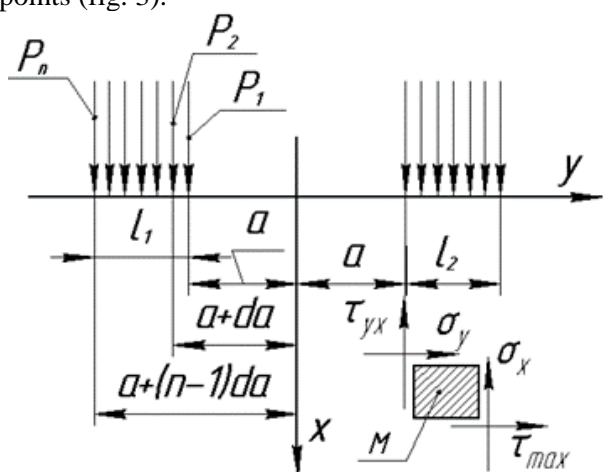


Fig. 3. The scheme of determining the tenses in elementary volume of semi- space, loaded by two blocks of distributed loading (a pair of wheels):

$P_1, P_2, \dots, P_i$  – are the value of corresponding unit forces, H;  $a$  – is the distance of block beginning from the beginning of coordinates, m;  $da$  – is spacing among forces in a block, m;  $l_1, l_2$  – is blocks' width, m;  $\sigma_x, \sigma_y, \tau_{yx}$  – are normal and tangent tenses in elementary semi-space M, Pa;  $n$  – is a number of forces in a block of distributed load

As a result, a mathematic model of tense state was received from two blocks of distributed load in the form of:

$$\begin{cases} \sigma_x = \frac{G}{\pi} \left( \sum_{i=0}^n \frac{k_i x^2}{[x^2 + (y - a - i\Delta a)^2]^2} + \sum_{i=0}^n \frac{k_i x^2}{[x^2 + (y + a + i\Delta a)^2]^2} \right), \\ \sigma_y = \frac{G}{\pi} \left( \sum_{i=0}^n \frac{k_i (-y - a - i\Delta a)^2}{[x^2 + (y - a - i\Delta a)^2]^2} + \sum_{i=0}^n \frac{k_i (y + a + i\Delta a)^2}{[x^2 + (y + a + i\Delta a)^2]^2} \right), \\ \tau_{xy} = \frac{G}{\pi} \left( \sum_{i=0}^n \frac{k_i x (y - a - i\Delta a)}{[x^2 + (y - a - i\Delta a)^2]^2} + \sum_{i=0}^n \frac{k_i x (y + a + i\Delta a)}{[x^2 + (y + a + i\Delta a)^2]^2} \right), \end{cases} \quad (1)$$

where  $G$  – is loading on the wheels' axle, H;  
 $l_i$  – is the width of a plot on which the distributed load was exerted, m

$k_i$  – is a weight coefficient which is determined as:  $k_i = P_i / P_0$  ( $P_0$  – according to rationing will be:  $P_0 = Gl / (l_1 + l_2 + l_3)$ );

$x, y$  – are coordinates of an elementary plot of semi-space M (fig.1) for which the indexes of normal and tangent tenses are determined, m.

According to the system (1), a sum of normal tenses, which characterizes the change of a tense state of the environment that is under investigation, under the weight of a pair of wheels, is determined on a vertical surface of soil semi-space as:  $I_I = \sigma_I = \sigma_x + \sigma_y$ , where  $I_I$  – is an invariant of a full tensor of tenses (a sum of normal tenses  $q_i$ ), Pa. And a maximum shifting tension  $\tau_{max}$  in a particular point of this surface will be:

$$\tau_{max} = \sqrt{\left( \frac{\sigma_x - \sigma_y}{2} \right)^2 + \tau_{xy}^2}. \quad (1)$$

The solutions of the equation make it possible to replicate a numerical model and imitation experiment to study the tense state of compacted soil profile according to the condition:

$$\begin{cases} \lim_{\sigma_x + \sigma_y \rightarrow \sigma_H} \frac{G_i}{q_i} = l_{opt}, \\ \lim_{\tau_{max} \rightarrow [\tau]} \frac{G_i}{q_i} = l_{opt}, \end{cases} \quad (3)$$

where  $G_i$  – is a weight of a machine and tractor unit that falls on wheel, H;

$q_i$  – is  $i$ - wheel's pressure on the soil surface, Pa;

$l_{opt}$  – is an optimal wheel's footprint area,  $m^2$ ;

$\sigma_H$  – is the boundary of soil's current, Pa;

$[\tau]$  – is permissible tangent tenses, Pa.

The application of a system (1) makes it possible to replicate a numerical experiment on optimization of the constructive and performance parameters of a mobile farm vehicle's wheel as to minimization of the levels of intensity of soil environment's tension.

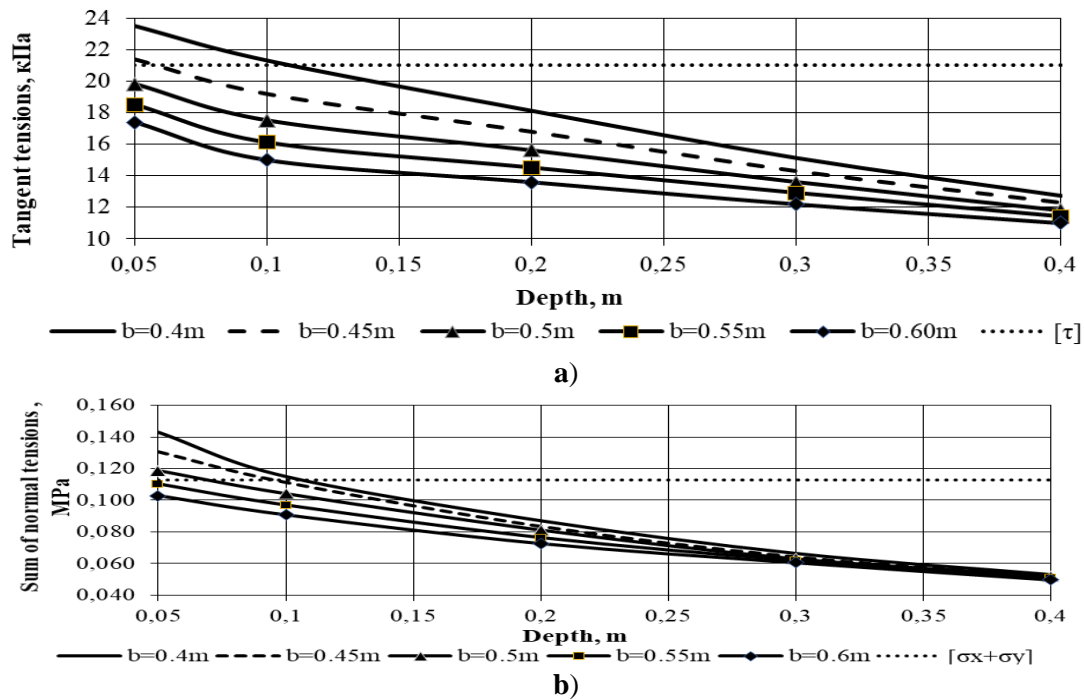


Fig. 4. Change of a sum of normal tensions (a) and tangent tensions (b) at depth

When solving the system (1), the change of the intensity level of soil environment tension at depth  $H=x$ , depending on the width  $b$  of wheel's footprint area contact with soil (fig. 4), was determined.

The current's boundary of sod-podzol sandy-loam soil which does not cause the non-renewable changes of the structural state of soil's root layers, for soil layer 0...10 is  $\sigma_{it} < 0.113$  MPa. Permissible tangent tensions (taking into account the moment of rolling) are  $\tau < 0.021$  MPa. Taking this into account,

it has been found that under maximum load on a wheel up to 28 kH (common to tractors of pulling power type 3) the width of a contact footprint has to satisfy the condition  $b \geq 0.55$  m.

When choosing the type of tires which satisfy this requirement, the normal and relative tires' deflections and the width of a contact footprint depending on pressure in a tire (fig. 5) were analyzed and a system (4) was received.

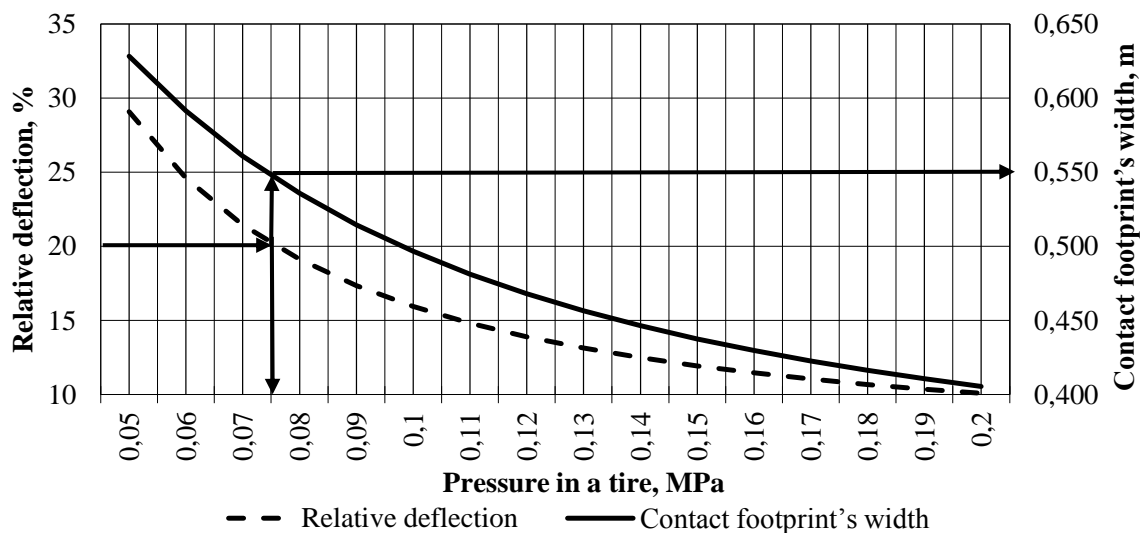


Fig. 5. The dependence of a change of contact footprint's width and of relative deflection on tension for a tractor's wheel type 3

$$\begin{cases} z_w = 1050p_w^2 - 327.7p_w + 42.54 \leq [z_w] = 20\%, \\ b = 10p_w^2 - 3.4p_w + 0.783 \geq 0.55. \end{cases} \quad (1)$$

When solving the system (4), the rational wheel's parameters were received. The use of this wheel does not result in non-renewable changes of the structural state of an agricultural soil layer (table 1).

Table 1. Rational wheel's parameters

Parameter	Designation	Dimension	Indexes
Rational pressure in a tire	$p_w$	MPa	0,075
Minimal width of a contact footprint	$b$	m	0,55
Maximal relative deflection of tire's dome	$z_w$	%	20
Type	28,1R26	-	-
Diameter	$D$	mm	1735±17
Width	$B$	mm	750
Profile height	$H$	mm	537

On the basis of the above mentioned characteristics of sod-podzol sandy loam soil, by means of the analysis of the numerical experiment's results, it has been determined that the use of a tire of type 28.1R26 for a tractor of pulling power type 3 under operating pressure  $p_w = 0.073$  MPa, does not cause non-renewable changes of the structural state of the agricultural soil layers.

### Conclusions

The results of the scientific research and of the practical experience testify to a close correlation link between a compressing effect of the drive systems of energy charged mobile agricultural machinery and the processes of upper soil degradation. The decline of the levels of technogeneous compression of mobile agricultural machinery on soil can be achieved by means of complex optimization of the construction parameters of the mobile machinery's wheels and by a corresponding standardization of their operating features.

A numerical simulation experiment made it possible to determine the basic rational parameters of a tractor's wheel of pulling power type 3, used while cultivating sod-podzol sandy loam soils:

working pressure in a tire is 0.075 MPa, a minimal width of a contact footprint is 0.55 m. Under these conditions the compressing tensions in soil under the wheel are lower than a tension boundary of form-changing of the microstructure and do not exceed 0.113 MPa.

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#### ОБҐРУНТУВАННЯ НАПРУЖЕНОГО СТАНУ ҐРУНТУ ПРИ ВЗАЄМОДІЇ ІЗ КОЛІСНИМИ РУШІЯМИ

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На полях широко використовуються машинно-тракторні агрегати, що складаються із важких тракторів та відповідних їм агрегатів. Використання таких машинно-тракторних агрегатів забезпечує зниження енерговитрат та скорочення витрат праці. Проте рушії важкої техніки активно деформують та ущільнюють ґрунт, що призводить до зміни агрономічно цінної структури ґрунту та до значного погіршення агроекологічного стану ґрунту. Застосування важких машинно-тракторних агрегатів вимагає встановлення для колісних рушіїв оптимальних конструкційних параметрів. Оптимізовані рушії сприятимуть зменшенню переущільненню та руйнуванню родючого шару ґрунту.

В статті розглянуто взаємодію із ґрунтом пари колісних рушіїв та розроблена схема для визначення полів напружень для прикладеного вертикального навантаження. Сформоване

завдання для розрахунку напруженого стану ґрунтового середовища. Сформоване завдання дозволяє визначити рівень напруженого стану під колісними рушійми машинно-тракторних агрегатів. Визначення рівня напруженого стану дозволяє знайти й обґрунтувати параметри колісних шин. Використання таких шин дозволить забезпечити рівень нормальних напружень в ґрунті нижче допустимих.

У результаті рішення оберненої контактної задачі за умови рівномірного розподілення контактних напружень, отримано математичну модель. Рішення отриманої математичної моделі дозволяє виконати комп'ютерне моделювання впливу ширини колісних рушіїв машино-тракторних агрегатів на напруження, які виникають в ґрунті. Отримана модель є універсальною та дозволяє виконувати дослідження колісних рушіїв різного типорозміру. Виконано теоретичне моделювання роботи машинно-тракторного агрегату. Отримано розподіл напружень в ґрунтовому середовищі.

**Ключові слова:** колеса, машинно-тракторний агрегат, нормальні напруження, дотичні напруження, структура ґрунту

#### ОБОСНОВАНИЕ НАПРЯЖЕННОГО СОСТОЯНИЯ ГРУНТОВ ПРИ ВЗАИМОДЕЙСТВИЯ С КОЛЕСНЫМ ДВИЖИТЕЛЕМ

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На полях широко используются машинно-тракторные агрегаты, состоящие из тяжелых тракторов и соответствующих им агрегатов. Использование таких машинно-тракторных агрегатов обеспечивает снижение энергозатрат и сокращение затрат труда. Однако двигатели тяжелой техники активно деформируют и уплотняют почву, что приводит к изменению агрономически ценной структуры почвы и к значительному ухудшению агроэкологического состояния почвы. Применение тяжелых машинно-тракторных агрегатов требует установки для колесных

*двигателей оптимальных конструкционных параметров. Оптимизированные двигатели будут способствовать уменьшению переуплотнением и разрушению плодородного слоя почвы.*

*В статье рассмотрено взаимодействие с почвой пары колесных двигателей и разработана схема для определения полей напряжений для приложенного вертикальной нагрузки. Сформулирована задача для расчета напряженного состояния почвенной среды. Сложившаяся задача позволяет определить уровень напряженного состояния под колесными двигателями машинно-тракторных агрегатов. Определение уровня напряженного состояния позволяет найти и обосновать параметры колесных шин. Использование таких шин позволит обеспечить уровень нормальных напряжений в почве ниже допустимых.*

*В результате решения обратной контактной задачи при условии равномерного*

*распределения контактных напряжений, получена математическая модель. Решение полученной математической модели позволяет выполнить компьютерное моделирование влияния ширины колесных двигателей машинно-тракторных агрегатов на напряжения, возникающие в почве. Полученная модель является универсальной и позволяет выполнять исследования колесных двигателей разного типоразмера. Выполнено теоретическое моделирование работы машинно-тракторного агрегата. Получено распределение напряжений в грунтовой среде.*

**Ключевые слова:** *колеса, машинно-тракторный агрегат, нормальные напряжения, касательные напряжения, структура почвы*