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Automated Tire Pressure Control System for Multi-Purpose Wheeled Vehicles

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Abstract. The cross-country capability of multi-purpose wheeled vehicles is one of the most important operational properties of these technical objects. In many ways, it is determined by their traction characteristics. There are a number of ways to improve traction and coupling properties of multipurpose wheeled vehicles, the main ones are the use of various kinds of traction control systems, blocking of interaxle and interwheel differentials, the use of ballast and several others. Recently, one of the ways to improve the traction properties and cross-country ability of vehicles on soils with weak load-bearing capacity is a regulation of air pressure in the tires of the driving wheels of multi-purpose wheeled vehicles. The paper describes the process of interaction of the wheel mover with the ground surface when the air pressure in the tire changes. The influence of air pressure on the traction properties of wheeled vehicles is established. The system of automatic control of air pressure in tires of mobile cars depending on road conditions is offered. The use of the proposed regulation principle will significantly increase the cross-country ability of multi-purpose wheeled vehicles in heavy traffic conditions, eliminating the subjective factor in the person of the vehicle operator.

Keywords: automatic regulation, tire, air pressure, propulsion, traction and coupling properties

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Автоматизированная система регулирования давления воздуха в шинах многоцелевых колесных машин

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Реферат. Проходимость многоцелевых колесных машин – одно из важнейших эксплуатационных свойств данных технических объектов. Во многом она определяется их тяговыми характеристиками. Известен ряд способов повышения тягово-сцепных свойств многоцелевых колесных машин, среди которых – применение различного рода противобуксовочных систем, блокировка межосевых и межколесных дифференциалов, использование балласта и ряд других. Один из способов повышения тягово-сцепных свойств и проходимости машин по грунтам со слабой несущей способностью, который получил развитие в последнее время, – это регулирование давления воздуха в шинах ведущих колес многоцелевых колесных машин. В статье приводится исследование процесса взаимодействия колесного движителя с грунтовой поверхностью при изменении давления воздуха в шине. Установлено влияние давления воздуха на тягово-сцепные свойства многоцелевых колесных машин. Предложена система автоматического регулирования давления воздуха в шинах мобильных машин в зависимости от дорожных условий. Использование предложенного принципа регулирования позволит существенно повысить проходимость многоцелевых колесных машин в тяжелых условиях движения, исключив субъективный фактор в лице оператора транспортного средства.

Ключевые слова: автоматическое регулирование, шина, давление воздуха, движитель, тягово-сцепные свойства

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Introduction

It is known that the air pressure in the tires of multi-purpose wheeled vehicles (MWV) determines the shape and size of the contact fingerprint and affects their traction and coupling qualities and patency on the supporting surface. This process is accompanied by slipping and a change in the strength of resistance to movement due to deformation of the soil. With a decrease in pressure, the supporting surface of the tire increases and the pressure of the propulsion on the ground surface decreases, which leads to an improvement in the traction and coupling properties and throughput of the MWV. This is especially evident when driving on soils with weak bearing capacity. On the contrary, the increase in pressure when MWV moves along artificial roads such as concrete, asphalt, stone or rolled dirt roads when a track is not formed improves the efficiency of the machine. Tire air pressure regulation is currently carried out manually by the driver when the car is moving in different road conditions. However, when the MWV moves on soils with weak bearing capacity, the driver does not always have time to catch the moment of decrease in the tangential traction force Fк with an increase in skidding epe, which leads to loss of patency or due to loss of adhesion of the mover to the supporting surface or landing on the bottom due to the increase in the track depth. Based on the results of an analysis of modern studies on soil mechanics when a dynamic load is applied to them, a set of dependencies is formed that determine the interaction of driven sprockets with the ground surface. The main ones are soil resistance to compression and shear when applying dynamic loads. As a method, a theoretical study of the traction and coupling properties and patency of wheel propulsions when driving on dirt surfaces has been adopted. The result of theoretical studies is the creation of an electronic device that monitors the moment of decrease in traction force or complete slipping and gives a signal to reduce air pressure in the tires, and, conversely, to increase pressure when the machine enters a solid supporting surface. Creation of a system for automatic regulation of air pressure in MWV tires depends on road conditions.

The process of interaction of the propulsion multi-purpose wheeled vehicles with a soil surface

To determine the favorable moment of turning on or off the air flow valve in the tire, it is necessary to determine the adhesion properties of the propulsion, slipping and track depth. These properties are determined, on the one hand, by the system-forming parameters of the MWV, such as: machine weight, engine power, propulsion structure, etc. On the other hand, they depend on the physical and mechanical properties of the soil surface, such as: structure and mechanical composition, humidity, soil resistance to compression and shear [1–3].

The most appropriate real conditions are the dependencies proposed by V. V. Katsygin [4, 5], namely:

– normal soil compression stress σ is determined by the formula

$$\sigma = \sigma_0 \,\mathrm{th}\left(\frac{k}{\sigma_0} h\right),$$

where σ_0 – bearing capacity of the soil, N/m^2; k – coefficient of volumetric crushing of the soil, N/m^3; h – immersion depth of the stamp, m;

– shear stress τ arising from the deformation of the soil are determined by the expression

$$\tau = f_{sk} q_x \left(1 + \frac{f_p}{\mathrm{ch}\,\dfrac{\Delta}{k_\tau}}\right) \mathrm{th}\,\frac{\Delta}{k_\tau},$$

q_x – pressure of the wheel on the ground, N/m^2; f_{sk} – coefficient of sliding friction; f_p – rest friction coefficient; k_τ – soil deformation coefficient, m; Δ – shear strain, m.

A graphical representation of the dependence of soil compression stresses is shown in Fig. 1.

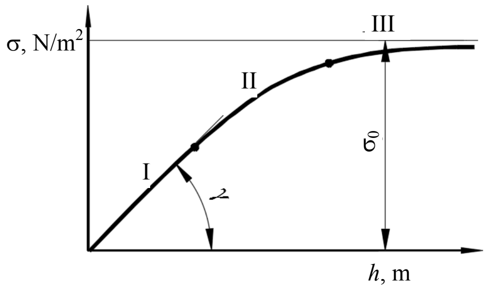

Fig. 1. Dependence of compression stresses on deformation (k = tgγ)

Fig. 1 shows that there are three sections of this dependence: the first section reflects elastic deformation; the second is plastic; the third is the flow of soil.

A graphical representation of the dependence of shear stresses arising from soil deformation is shown in Fig. 2.

Figure 2 shows that the shear stresses reach a maximum at some strain Δ_0, and then decrease. This phenomenon is explained by the fact that in section I the soil is compacted (static friction), and in section II it is shifted (sliding friction).

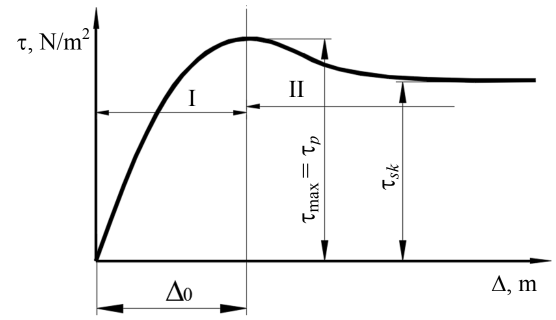

Fig. 2. The dependence of shear stress on deformation

Using these dependencies, prof. V. V. Guskov [6–8] developed a system of equations that describes the process of interaction between the driving and driven wheels of the propulsion device with a ground surface, and which allow to determine the traction and coupling properties and the permeability of MWV on soil surfaces. These equations are given below.

The force of resistance to movement F_{spr} due to the formation of a track with depth h

$$F_{spr} = \int_0^{h_0} b\sigma_0 \operatorname{th}\left[\frac{k}{4b\sigma_0} D_{pr} \ln\left(\frac{D_{pr}-h}{D_{pr}-h_0}\right)\right] dh, \quad (1)$$

where b – width of the wheel, m; $D_{pr} = 2r_{pr}$ – reduced wheel diameter, m; h_0 – soil deformation at the corresponding vertical load, m; σ_0 – soil bearing capacity, N/m^2; k – coefficient of volumetric crushing of the soil, N/m^3.

The vertical load leading to soil deformation by h_0

$$G = \int_0^{h_0} \frac{b\sigma_0 \left(D_{pr}-2h\right)}{2\sqrt{D_{pr}h - h^2}} \operatorname{th}\left[\frac{k}{4b\sigma_0} D_{pr} \ln\left(\frac{D_{pr}-h}{D_{pr}-h_0}\right)\right] dh. \quad (2)$$

The reduced radius of the wheel can be determined by the expression

$$r_{pr} = \frac{h^2 + \left[2\sqrt{r_0 h_{sh} - h_{sh}^2} + \sqrt{2r_0 h - h^2}\right]^2}{2h}. \quad (3)$$

In this expression, the value of tire deformation under load can be determined by the Heideckel formula

$$h_{sh} = \frac{G}{2\pi p_{sh}\sqrt{r_0 r_c}}, \quad (4)$$

where p_{sh} – tire pressure, Pa; r_c – radius of the tire section, which can be equated to half the width of the tire, m, those $r_c \approx b/2$.

The tangential traction force (driving force) is determined according to the formula

$$F_k = \int_0^{L_{pr}} b f_{sk} q_x \left(1 + \frac{f_p}{\operatorname{ch}\frac{\delta_x x}{k_\tau}}\right) \operatorname{th}\frac{\delta_x x}{k_\tau} dx, \quad (5)$$

where L_{pr} – reduced length of the supporting part of the wheel, m; q_x – mover pressure on the ground, N/m^2; f_p, f_{sk} – coefficients of friction of rest and sliding; δ_x – slipping of the wheel at the point of contact with the x coordinate; k_τ – strain coefficient.

The reduced length of the wheel support is calculated as:

$$L_{pr} = r_0 \operatorname{arctg}\sqrt{\frac{2r_0 h - h^2}{r_{pr} - h}} + \sqrt{2r_0 h}, \quad (6)$$

where h – rut depth, m.

A typical dependence obtained when calculating the expressions (1)–(6) of the tangential traction force F_k from slipping δ of the drive wheels is shown in Fig. 3.

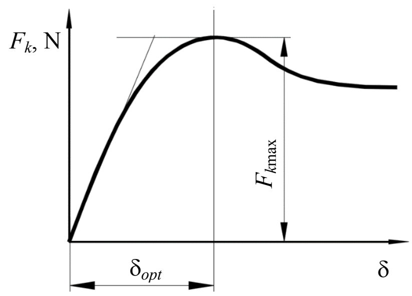

Fig. 3. The dependence of the tangential force on slipping when driving wheel on a dirt surface

Fig. 3 shows that the tangential traction force F_k increases depending on slipping δ to a certain value δ_{opt}, and then begins to decrease. This is due to the fact that when a tire with lugs interacts with the ground surface, the latter move the soil in the direction opposite to the movement of the machine and in the section from 0 to δ_{opt}, the driving force is proportional to the shear forces T_{sd}.

Upon reaching slipping δ_{opt}, the lugs cut off the soil "bricks" and an "earth" wheel is formed, i. e. shear friction T_{sd} is replaced by sliding friction T_{sk}. It is known that $T_{sd} \geq T_{sk}$ [9–11].

Thus, when slipping a wheel, there are two modes of slipping (Fig. 3):

– traction increases with increasing slip;

– the traction force drops and tends to a constant value, due to the friction forces of the "earthen" wheel with a dirt surface.

Fig. 4 shows one of the options for the proposed system of automatic regulation of air pressure in the tires of mobile cars.

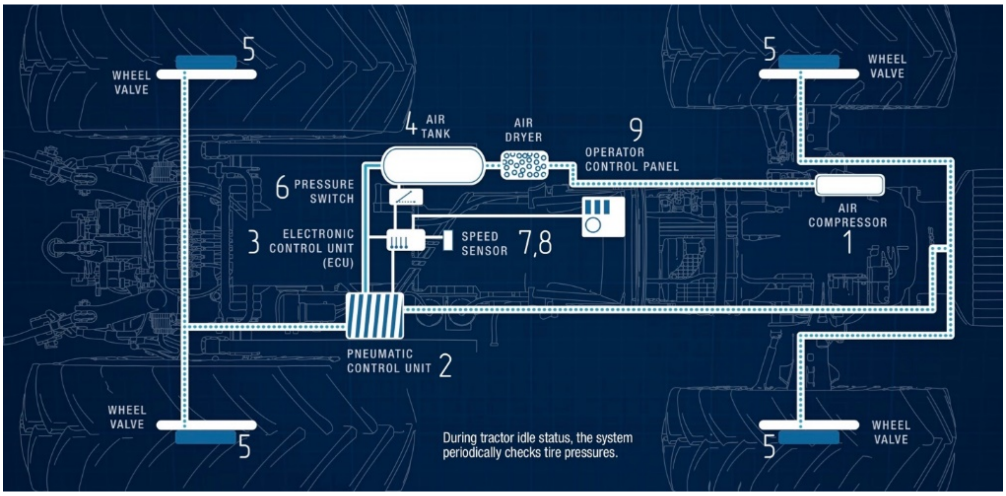

Fig. 4. Schematic diagram of an automatic system tire pressure regulation: 1 – compressor; 2 – pressure regulator; 3 – triple safety valve; 4 – receiver; 5 – tire valve; 6 – pressure sensor; 7 – real sensor speed; 8 – theoretical speed sensor; 9 – electronic unit

Air from the compressor 1 is supplied to the receiver 4, from which, using the bus valve 5, controlled by the electronic unit 9, directly to the bus. The air pressure in the tires is controlled by the electronic unit according to the signals from the real speed sensor 7, theoretical speed sensor 8 and torque sensors 6 by controlling the tire valves.

CONCLUSIONS

1. It is established that the regulation of air pressure in the tires of mobile cars affects their traction and coupling properties and patency.

2. Manual control has a number of disadvantages when moving the machine on various soil surfaces, when a rapid change in pressure is required.

3. It is possible to create a pressure control system that provides automatic tire pressure control depending on road conditions.

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