Improvement of Cross-country Capability of All-wheel Drive Vehicles by Means of Decentralization of Regulation of Air Pressure in Tires

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***Abstract*— Cross-country capability of multi-purpose vehicles is based on various characteristics, namely: the base and the profile cross-country ability, maneuverability, stability and controllability as well as traction and speed properties, such as engine power, maximum speed and average speed of movement. The main component, limiting the level of mobility of the multi-purpose vehicles, is their bearing cross-country capability that is primarily determined by design, stress, dimensional and stiffness parameters of a wheel mover, as well as, by tread pattern and tire design, physical and mechanical characteristics of support surface. It is obvious that improvement of operational performance is primarily possible due to development of the wheel mover. Indeed, all processes, occurring in aggregates and components of the vehicles, to implement their movement are completed and realized in tire contact with supporting surface. In this paper we investigate the problem of increasing the cross-country capability of multi-purpose vehicles and perspective way for its decision. Besides, we consider some results of mathematical modeling of a single-wheeled mover. In addition, we conduct an experiment of rolling of the single-wheeled mover on a deformable support surface as a function of load, the passage number and the air pressure in the tire.**

***Index Terms*— Cross-country capability, all-wheel drive vehicles, air pressure**

I. INTRODUCTION

With increasing of vehicle capacity and when driving on deformable support surfaces, problems with level of cross- country ability are obvious. The cross-country ability of vehicles is always the higher the lower the pressure exerted by wheels on ground, and the lower internal pressure in tires. Therefore, to increase the cross-country ability of a vehicle while driving it should be reduced the internal pressure. For this aim constructively provided air-pressure control in tires is used. Central control system for air pressure in tires improves vehicle's ability to move, regardless of the road conditions, road surface, soil type and climatic conditions.

A consequence of straight-line movement of a vehicle on a deformable support surface is that there is a natural change in characteristics of the support surface (soil degradation, etc.) with passage of each subsequent wheel. Thus at successive wheel pass, depth of rut is increasing, causing increasing in friction force depending on the soil type and its characteristics and increasing losses of power to overcome this resistance.

In this connection, it is assumed that while driving on a deformable support surface there is the need to provide the pressure in tires of wheel mover individually for each wheel, depending on physical and mechanical characteristics of the ground supporting surface, the load attributable to each wheel, number (sequence) of passage of wheels in ruts formed by them.

II. THE METHOD OF SOLVING OF THE PROBLEM

The specific of movement conditions of a multi-purpose vehicle determines, while we investigate rolling resistance, the need to take into account hysteresis loss in the tire deformation, and loss from soil deformation. In this case, the rolling resistance coefficient can be represented by the sum of two terms:

$$f = f_t + f_g, \tag{1}$$

where f_t is the coefficient of tire rolling resistance;

f_g is the coefficient of resistance to soil deformation.

Influence of design and operational parameters it is appropriate to allocate to specific functions. They can be considered with help of functional factors in the

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form k_t , k_g . Then the expression (1) can be represented as follows:

$$f = k_t \cdot f_{ot} + k_g \cdot f_{og}, \qquad (2)$$

here k_t is correction function of the coefficient of tire rolling resistance;

k_g is correction function of the coefficient of resistance to soil deformation;

f_{ot} is the coefficient of tire rolling resistance in slave mode with nominal load and air pressure in the tire;

f_{og} is the coefficient of resistance to soil deformation in slave mode with nominal load and air pressure in the tire.

The correction functions k_t and k_g can be represented as the product of partial correction functions:

$$k_t = k_{tRz} \cdot k_{tpw} \cdot k_{ty} \cdot k_{tq} \cdot k_{tv} \cdot k_{tM}, \qquad (3)$$

where k_{tRz} is private correction function of the coefficient of tire rolling resistance taking into account the change in the load R_z ;

k_{tpw} is private correction function of the coefficient of rolling resistance taking into account the change of air in tire pw;

k_{ty} is private correction function of the coefficient of tire rolling resistance taking into account the phenomenon of tire slip;

k_{tq} is private correction function of the coefficient of tire rolling resistance taking into account the movement over uneven support surface;

k_{tv} is private correction function of the coefficient of tire rolling resistance taking into account the impact of velocity v;

k_{tM} is private correction function of the coefficient of tire rolling resistance taking into account the transfer of torque M :

$$k_g = k_{gRz} \cdot k_{gpw} \cdot k_{gy} \cdot k_{tv} \cdot k_{tM} \cdot k_{gn},$$

where

k_{gRz} is private correction function of the coefficient to soil deformation taking into account the change in the load R_z ;

k_{gpw} is private correction function of the coefficient to soil deformation taking into account the change of air in tire pw;

k_{ty} is private correction function of the coefficient to soil deformation taking into account the phenomenon of tire slip;

k_{tv} is private correction function of the coefficient of tire rolling resistance taking into account the impact of velocity v;

k_{tM} is private correction function of the coefficient to soil deformation taking into account the transfer of torque M ;

k_{gn} is private correction function of the coefficient to soil deformation taking into account number of wheel passage on the ground.

The coefficients of tire rolling resistance and deformation of ground in slave mode with nominal load and air pressure in tire, as well as the correction private functions were determined by analysis of the literature [1-3] and experimental studies of interaction of a single wheeled mover with different types of surfaces [5-8]. Analysis of the results of the pilot study revealed the nature of the effect on the rolling resistance coefficient of the normal load, air pressure, torque transmission, kind of surface and set the values of the respective partial correction functions:

$$k_{tRz} = A_{Rz} + B_{Rz} \cdot Rz^2;$$

$$k_{tpw} = A_{pw} \cdot pw^{B_{pw}};$$

$$k_{ty} = 1 + \frac{k_y \cdot \delta_y^2}{f_{ot} \cdot R_z};$$

$$k_{tv} = 1 + \frac{k_v \cdot v^2}{f_{ot}};$$

$$f_{og} = A_{og} \cdot c^{B_{og}};$$

$$A_{og} = 0.11 \cdot \mu^2 - 0.19 \cdot \mu + 0.14;$$

$$B_{og} = -0.65 \cdot \mu^2 + 1.27 \cdot \mu - 0.97;$$

$$k_{gRz} = \left(\frac{R_{zi}}{R_{z0}} \right)^{\frac{1}{2 \cdot \mu + 1}};$$

$$k_{gpw} = A_{gpw} \cdot pw^{0.5} + B_{gpw};$$

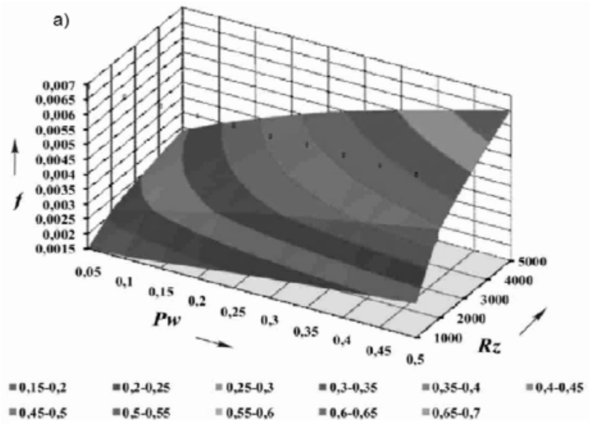
$$k_{gn} = A_{gn} \cdot n^{B_{gn}}.$$

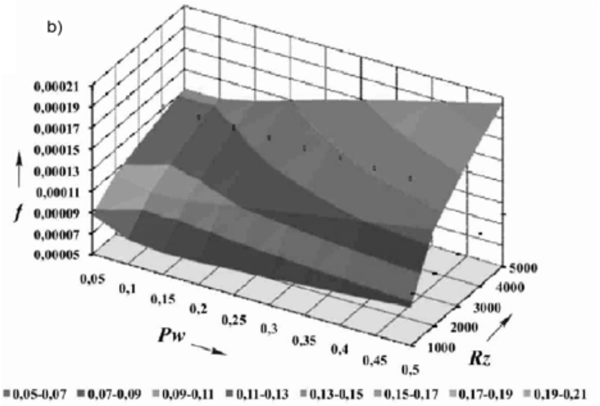
Using the air pressure control system in tires of multi-purpose vehicles allows reducing depth of the track and the tire rolling resistance. At the same time the value of the optimum tire air pressure depends on the load on wheels and the weight distribution of the car.

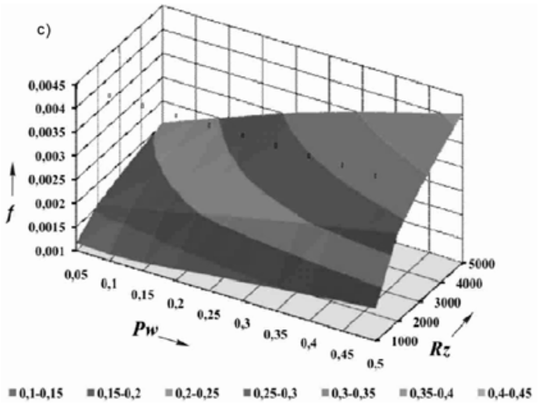
On the basis of the developed mathematical model of rolling single wheeled mover on deformable ground under certain load and dimensional parameters, indicators of stiffness characteristics, as well as the physical and mechanical parameters of the soil with help of the mathematical package MathCAD, it was calculated how the air pressure (P_w) in tires influences the tire rolling resistance (f) while successive passes and different vertical loads (Rz).

III. ANALYSIS OF THE RESULTS

The results of the mathematical modeling of single-wheeled mover [9-11] and the conducted experiment taking into account the limitations and assumptions allowed getting a function of the tire rolling resistance depending on the load, acting on wheel, air pressure in the wheel and number of the passage while rolling on a deformable support surface with different types of soils. The simulation results are presented in Figure 1.







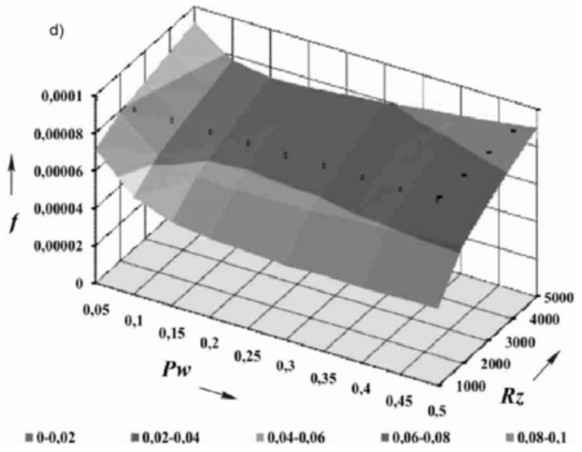


Fig.1. Dependence f as a function of Rz, Pw and number of passages on: (a) - the first passage, (b) - the second passage, (c) - the third passage, (g) - the fourth passage

Intervals for values of air pressures in the wheel tire (Pw, MPa), corresponding to the minimum value of the coefficient of resistance obtained by conducting the experiment at the set load and depending from the number of wheel passage on loam are presented in Table I.

TABLE I
DATA OF THE EXPERIMENT OF ROLLING OF SINGLE WHEELED MOVER ON LOAM

Load acting on wheel, kg	Number of passage			
	the first	the second	the third	the fourth
1000	0,05-0,10	0,05-0,10	0,15-0,20	0,30-0,35
2000	0,05-0,10	0,05-0,10	0,10-0,15	0,20-0,25
3000	0,05-0,10	0,05-0,10	0,10-0,15	0,15-0,20
4000	0,05-0,10	0,05-0,10	0,05-0,10	0,15-0,20
5000	0,05-0,10	0,05-0,10	0,05-0,10	0,15-0,20

Tests, done for Russian commercial vehicle KAMAZ-5350 (Figure 2) on a typical deformable support surface with varying load on wheel axles of the vehicle, with the set air pressures in the tires in accordance with the requirements of normative-technical documentation of the manufacturer [4] and recommended based on the results of study of pressure for the wheels of each axle, allow us to estimate the effectiveness of the proposed method for increasing of the cross-country ability due to the decentralization of the air pressure in the tires.

Values of air pressure in tires recommended by the results of the study for the wheels of each axle when driving on loam are presented in Table II.

TABLE II
RECOMMENDED VALUES OF AIR PRESSURE IN THE TIRES (PW, MPA) FOR WHEELS OF DIFFERENT AXLES WHEN DRIVING ON LOAM

R_z, kg	Location of wheel in wheel formula		
	1	2	3
1000	0,08-0,10	0,08-0,10	0,15-0,20
2000	0,08-0,10	0,08-0,10	0,10-0,15
3000	0,08-0,10	0,08-0,10	0,10-0,15
4000	0,08-0,10	0,08-0,10	0,05-0,10

The conducted experimental evaluation of increasing of the cross-country ability by decentralizing control of air pressure in the tires showed a significant increase in cross-country performance.

Using the proposed method to improve the cross-country capability of the vehicle KAMAZ-5350 due to the decentralization of the air pressure control in tire provides

1.05 - 1.07 times bigger the value realized by traction on the hook and in 1.04 - 1.07 times the reduction in fuel consumption compared to with vehicle driving with the air pressure in tires in accordance with the requirements of normative and technical documentation for this vehicle.

Fig.2. Fragments of experimental studies

V. CONCLUSION

1. The basis of the mathematical model of a single elastic wheeled mover rolling on deformable bearing surface is the principle of superposition, in which energy costs on the rolling wheel are divided on deformation of tire and deformation of a support surface. Influence of external factors in this model is practically considered through partial correction functions, received by experimental way.
2. Based on the calculated experiment performed using the developed mathematical model, it was found that for each selected type of the deformable support surface (loam with different degree of humidity and structure, wet river sand), combined with number of passage of a single elastic wheeled mover with a vertical load on it, there is a range of air pressure in the tire, providing the minimum energy consumption on its rolling.
3. The results of the experimental studies have shown a significant increase in traction on the hook of the tested vehicle, and a significant reduction in fuel consumption.
4. On the basis of the received data, the method for increasing permeability of multi-purpose vehicles is suggested, by the decentralized control of air pressure in tires as a function of load acting on wheels and their constructive position in the scheme of wheeled vehicle.

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