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CONTRIBUTION TO RESEARCH OF SPECIFIC PRESSURE BETWEEN TIRE AND ROAD IN MOTOR VEHICLES

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RESEARCH ARTICLE

ABSTRACT: One of the most important features of special motor vehicles is the possibility of movement outside the regular roads. In order to provide appropriate characteristics of mobility, such vehicles should, among other things, meet the requirements in terms of geometric parameters of mobility, traction characteristics, characteristics of stability, and the possibility of overcoming obstacles. As the contact between the tire and the road is very important for ensuring proper performance of motor vehicles, significant attention must be paid to it. Keeping this in mind, a model for approximation of average specific pressure between the tire and the deformable surface has been identified in this paper. In the coming period, research that is more detailed should be carried out in order to define similar models for different tires and road surfaces.

KEY WORDS: vehicle, tire, air pressure, radial load, average specific pressure

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PRILOG ISTRAŽIVANJU SPECIFIČNOG PRITISKA IZMEĐU PNEUMATIKA I TLA KOD MOTORNIH VOZILA

REZIME: Jedna od najvažnijih karakteristika specijalnih motornih vozila je mogućnost kretanja van uređenih saobraćajnica. Da bi se obezbedile odgovarajuće karakteristike prohodnosti, takva vozila treba da, između ostalog, ispune zahteve u pogledu geometrijskih parametara prohodnosti, vučnih karakteristika, karakteristika stabilnosti, kao i mogućnosti savladavanja prepreka. Kako je kontakt pneumatika i tla veoma značajan za obezbeđivanje odgovarajućih performansi motornih vozila, njemu se mora posvetiti značajna pažnja. Imajući to u vidu, u ovom radu je identifikovan model za aproksimaciju srednjeg specifičnog pritiska između pneumatika i deformabilne podloge. U narednom periodu treba izvršiti detaljnija istraživanja sa ciljem da se slični modeli definišu za različite pneumatike i podloge-puteve.

KLJUČNE REČI: vozilo, pneumatik, pritisak vazduha, radijalno opterećenje, srednji specifični pritisak

CONTRIBUTION TO RESEARCH OF SPECIFIC PRESSURE BETWEEN TIRE AND ROAD IN MOTOR VEHICLES

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1. INTRODUCTION

One of the most important features of special motor vehicles is the possibility of movement outside the regular roads. In order to provide appropriate characteristics of mobility, such vehicles should, among other things, meet the requirements in terms of geometric parameters of mobility, traction characteristics, characteristics of stability, and the possibility of overcoming obstacles. These wheeled vehicles are often equipped with special tires and systems for central air pressure regulation [1]. These systems, in addition to providing smaller specific pressure, also provide greater reliability of tires, as they provide compensation for air loss that can be caused by punctured tires.

The design of the tires should ensure, among other things, the lowest possible specific pressure. As the contact between the tire and the road is very important for ensuring the appropriate performance of motor vehicles, considerable attention must be paid to it [2-8]. Since the aim of this paper is to develop a method for calculating the specific pressure between the tire and the road, the results of some previous research will be considered.

The problem of contact between the tires and the dirt roads is explained in detail in [3]. The results of experimental research on truck tires have shown that as the tire air pressure and the radial load increase, the average specific pressure between the tire and the road also increases.

The book [9] is completely dedicated to terramechanics, especially to the calculation and measurement of actual road loads in various types of vehicles (military vehicles, trucks, passenger vehicles, tractors, etc.). The relationship between the tires and the deformable surface is especially emphasized.

In [10], the authors point out the importance of research of the relationship between the tire and deformable ground in trucks. A method for measurement of tire footprints on deformable ground and a software for data analysis have been developed.

The authors of [11] give an overview of conventional and unconventional procedures for measuring the specific pressure between the tires and the road. A method based on acoustic phenomena is specifically described.

The problem of modelling the relationship between the tires and the road was specifically considered in [12], while the interaction between the tires and the ground from the aspect of the influence of different types of road surface on the characteristics of motor vehicles was discussed in detail in [13].

In [14], the author investigates in detail the influence of the contact and the ground on the performance of agricultural tractors.

Considering the reviews of some of the materials published in this field, the conclusion can be made that this problem is still relevant today, especially with freight motor vehicles intended for off-road driving, as well as with agricultural machinery. Therefore, an acceptable model of average specific pressure between the tires and the deformable ground was defined in the paper, based on the existing experimental results from [3].

2. APPLIED METHOD

For further analysis, data from [3] are shown in Figure 1. They refer to the contact of the truck tire 11.00 R16XL and deformable ground (dirt road) with precisely defined composition of clay and sand, at different tire air pressures and different radial loads.

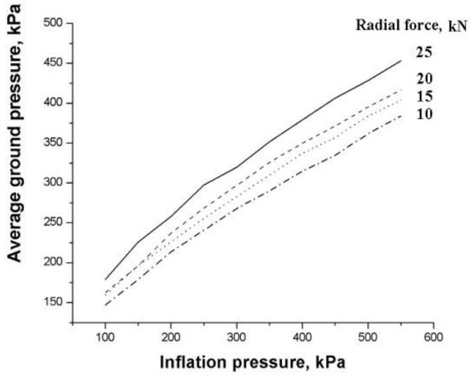

Figure 1: *Dependence of average specific pressure on tire radial force and tire inflation pressure* [3]

The analysis of data from Figure 1 shows that the average specific pressure between the tire and the ground increases with the increase of the tire inflation pressure and this is also happening with the increase in radial force.

Data from Figure 1 were digitized using the PlotDigitizer software and displayed in the form of 3D graphics in Figure 2.

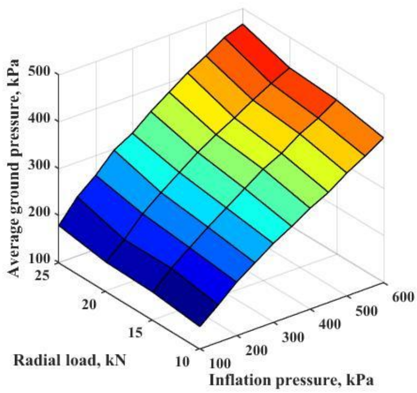

Figure 2: *3D graphics of dependence of the average specific pressure between the tire and the road on tire inflation pressure and radial force of data from [3]*

Figures 1 and 2 show that the dependence of the average specific pressure on tire inflation pressure and radial force is defined at a relatively small number of points, which is not sufficient for more precise analyses. In order to improve the accuracy, the number of points where the surface is defined is increased, so data from Figure 2 were approximated by 2D spline transforms and shown in 256x256 points, Figure 3.

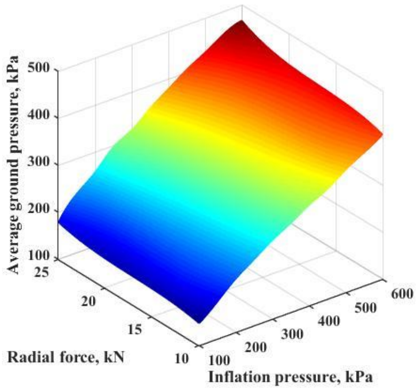

Figure 3: *Approximated data on dependence of average specific pressure between the tire and the road on tire inflation pressure and radial force defined in 256x256 points*

As average specific pressure from Figures 2 and 3 depends on two quantities - tire inflation pressure and radial force, their frequency spectra were also included in the analysis. Therefore, a 2D Fourier transform was performed using OriginPro software. The mentioned transform was performed for the data shown in Figure 3. Since information about the process is mainly carried out by the magnitude of the 2D Fourier transformation spectrum [15], the magnitude is shown, for illustration, in Figure 4.

Analysis of the data from Figure 4 shows the way the magnitude of the spectrum changes with the change of tire inflation pressure and radial force frequency. The peaks appear at the coordinate origin ($p_{\min}$, $Z_{\min}$) and at the points ($p_{\max}$, $Z_{\max}$) and ($p_{\min}$, $Z_{\max}$), where:

- $p_{\min}$, $p_{\max}$, kPa^{-1} are minimum and maximum inflation pressure frequency and
- $Z_{\min}$, $Z_{\max}$, kN^{-1} are minimum and maximum radial force frequency.

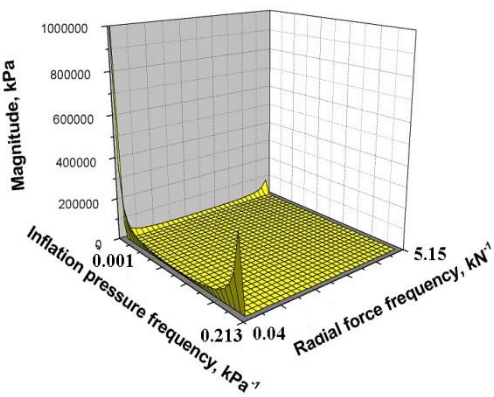

Figure 4: *Spectrum magnitude of 2D Fourier transform of approximated data*

Considering the previous analysis, further research was oriented on modelling the experimental data from Figure 1, using the “black box” method. The experimental data are represented by a function with unknown parameters, which are calculated using one of the identification methods [16-19].

To define the structure of the model, research was conducted with different polynomial shapes, and preliminary analyses showed that the smallest error occurs with the following model:

$$p_{spc} = \left(x_1 + x_2 \cdot p + x_3 \cdot p^2 + x_4 \cdot p^3\right) \cdot \left(x_5 + x_6 \cdot Z + x_7 \cdot Z^2 + x_8 \cdot Z^3\right), \quad 1)$$

where:

- p_{spc} is specific pressure, kPa,
- p is tire inflation pressure, kPa,
- Z is radial tire force, kN,
- x_i, $i = 1,8$ are polynomial parameters that should be identified.

The identification of unknown model parameters of the average specific pressure between the tire and the ground was performed using the identification method based on optimization principles [16], the block diagram of which is shown in Figure 5.

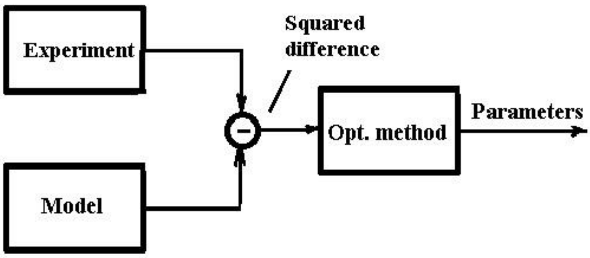

Figure 5: *Block diagram of the used method for identification of the parameters of the model for average specific pressure between the tire and the road*

Figure 5 shows that, in order to identify the parameters of the model of the mean specific pressure between the tire and the ground, it is necessary to have the results of experimental research. In this case, experimental data from [3] were used. Measurement errors were not taken into account, so they are not shown in the figure.

In order to identify the parameters of the model (1), the objective function was defined in the form of the square of the differences (2), and the unknown parameters were determined from the conditions of its minimization.

$$\Phi = \Sigma\left[p_{spc} - p_{\exp}\right]^2. \quad 2)$$

Minimization of the objective function was performed by the optimization method, whose block diagram is shown in Figure 6. The method itself is described in detail in [10-13].

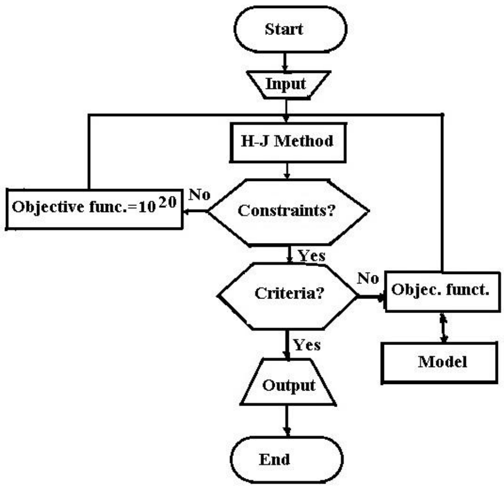

Figure 6: *Block diagram of the optimization method*

In this particular case, the Hooke-Jeeves method was used for optimization. During the process of parameter identification, penal functions [18] were used, with the introduction of limits of the parameter values $x_i \in [-100, 200]$, with the search step for the objective function of 10^{-5} and with the criterion of interrupting the iteration process of the Hooke-Jeeves method of 10^{-10}.

3. DATA ANALYSIS

Model parameters were calculated from the expressions (1) and (2) and listed in Table 1.

Table 1: *Identified parameters of the model (1)*

	X_1, kPa	X_2, –	X_3, kPa^{-1}	X_4, kPa^{-2}	X_5, –	X_6, kN^{-1}	X_7, kN^{-2}	X_8, kN^{-3}
	$2{,}05\cdot10^{3}$	$2{,}95$	$-6{,}77\cdot10^{-3}$	$6{,}7\cdot10^{-6}$	$-1{,}84\cdot10^{-2}$	$1{,}16\cdot10^{-2}$	$-2{,}53\cdot10^{-4}$	$3{,}14\cdot10^{-6}$

Minimum value of the objective function of $2{,}908\cdot10^{2}$ was calculated after 59 922 402 iterations.

Values of the mean specific pressure calculated at 256x256 points for the identified model parameters from Table 1 and based on expression (1), are shown in Figure 7. Analysis of data from Figures 3 and 7 shows that they preliminary describe data from Figure 3 with acceptable accuracy.

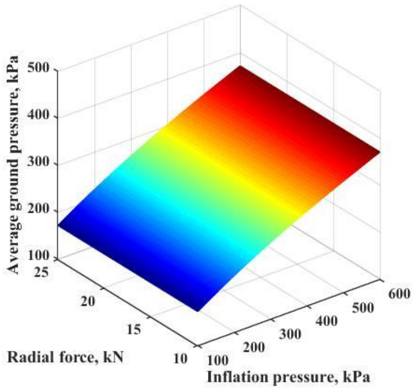

Figure 7: *3D chart of the model defined in 256x256 points*

In order to support this claim, relative errors of the model in relation to the initial experimental data [3] were calculated and presented in Figure 8.

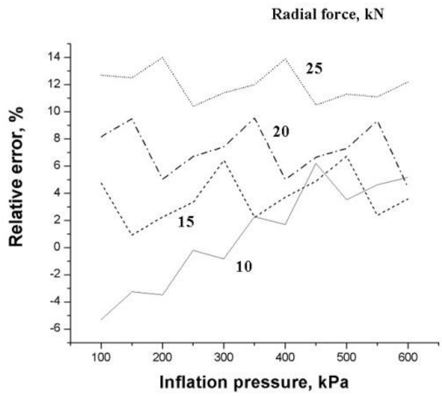

Figure 8: *Relative error of the model in relation to initial data from [3]*

By analysing data from Figure 8, it can be determined that the relative error ranges from -6% to 14% for the observed values of tire inflation pressure and radial force. The interval of relative errors is acceptable for identification of mathematical models.

For further analyses, a 2D Fourier transform was performed of the data shown in Figure 7, and the obtained spectrum magnitudes are shown in Figure 9.

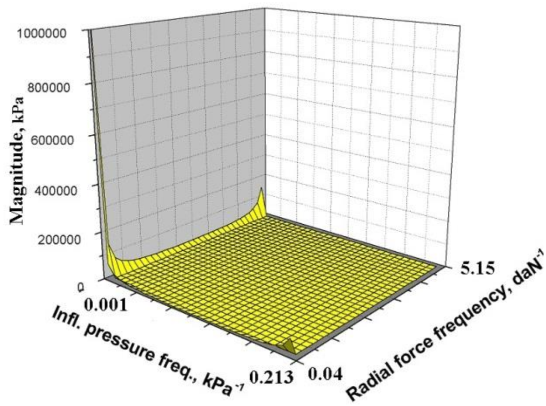

Figure 9: *Magnitude of 2D Fourier transform spectrum obtained using the model (1) in 256x256 points*

The analysis shows that there is a great similarity in character of data from Figures 4 and 9. This indicates that model (1) approximates data from Figure 3 in the frequency domain in satisfactory manner. Thus, it can be stated that the identified model can be used in the case of vehicles with tires of approximately the same dimensions when driving on a deformable surface. In the following period, a more detailed research should be performed in order to define similar models for different tires and road surfaces.

Finally, it should be noted that the procedure for calculating statistical errors is defined for the 1D Fourier transform in [20], while such procedures for Fourier transforms with multiple variables do not exist, so the analysis of the mentioned errors was not performed in this paper.

4. CONCLUSIONS

Based on the performed research, it can be concluded that the developed model of mean specific pressure between tires and deformable surface enables dynamic simulation with acceptable relative error. The identified model can be used in the case of vehicles with tires of approximately the same dimensions, when moving on a deformable surface. In the following period, a more detailed research should be performed in order to define similar models for different tires and road surfaces.

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