STUDY OF MODEL WITH SINGLE DEGREE OF FREEDOM FOR TRACTORS

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Abstract. The paper presents the mathematical modeling of the tractor wheel using a model with a single degree of freedom. The tractor is a complex mechanical system which, while moving, generates vibrations that are transmitted from the running path to the driver. The article analysis the main parameters of the road types a tractor can move on. A mathematical modeling program is used to analyze two driving wheels and two driven wheels used on the U-650 tractor. The program that implements the numerical model for the tractor wheel allows: tracing of the terrain profile for all five gear speeds of the tractor (slow and fast ranges), calculus of the tires elastic constants, the determination of the disturbing force amplitude, oscillatory movement of the wheel for each speed, calculus of the amplification factor and of the coefficient of transmissibility. The oscillatory movement parameters were determined for two driving wheels (one equipped with the Romanian tire and the other with GoodYear tire) and for one driven wheel, all used on the Romanian U-650 tractor.

Keywords: tractor, wheel, tire, road parameters.

Introduction

The tractor is a complex mechanical system which, while moving, generates vibrations that are transmitted from the running path to the driver [1].

The vibration amplitude and frequency determine the comfort level of the tractor driver and the normal reactions on the wheels.

Disturbances induced in the suspension system of the tractor caused by the relief bumps have a random character [2]. We can consider that the mathematical laws that characterize these disturbances are close to the periodic law. The irregularities of the running path give rise to shocks on the wheels, shocks that are transformed by the tires into oscillations [3].

The parameters of the main road types are given in Table 1.

Table 1

The parameters for the main types of roads

Category of road	Amplitude (h_0), mm	Wave length (l), m
Highway	10-20	10.00-15.00
Main road asphalt	10-20	1.00-2.00
Main road paved	30-40	0.15-0.30
Unpaved road	50-70	0.10-0.15

The characteristic parameters of the road change over time depending on the status of the road wear layer (Table 2).

Table 2

The road characteristic parameters depending on the status of wear

Road condition	Parameter characteristics				Mean square of h_0, cm
	Maximum values		Expected values		
	h_0, cm	l, m	h_0, cm	l, m	
Reduced wear	≤10	≤3.5	3-5	0.5-1.5	≤1.5
Strong wear	10-15	≤5	5-7	1-2.5	1.5-3
Total wear	>15	>5	7-10	1.5-3	>3

The wheel of the tractor is considered as a mechanic system with one degree of freedom, which has damped linear forced vibration (Fig. 1).

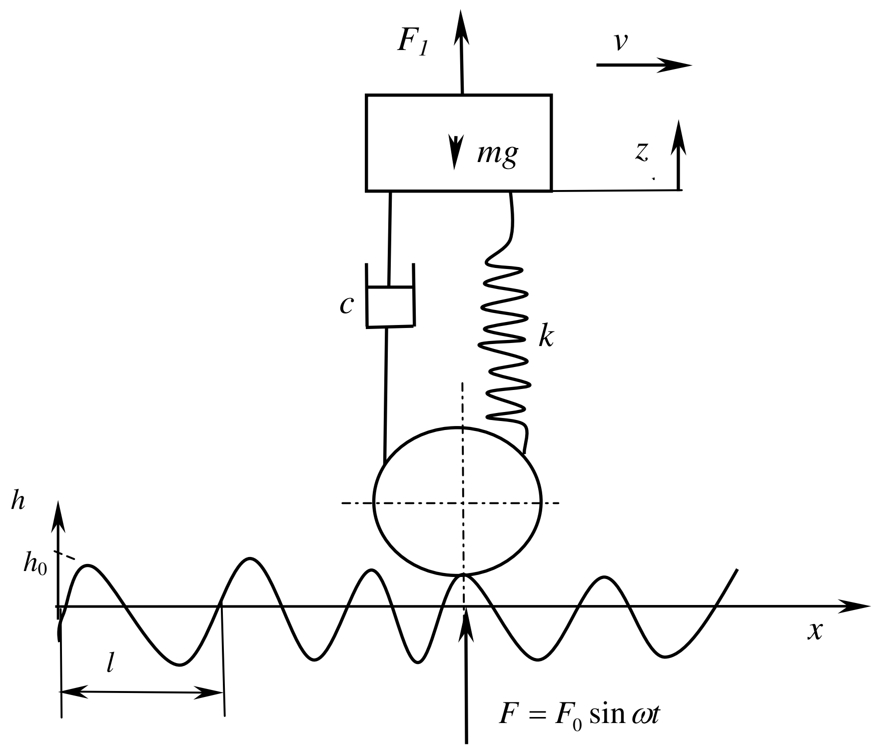

Fig. 1. **Model with one degree of freedom of wheel**

On the wheel of a tractor with mass m acts the disturbing force $F = F_0 \sin(\omega t - \varphi)$. The disturbing force expression is:

$$F(t) = kh_0 \sin \omega t + ch_0 \omega \cos \omega t \quad (1)$$

and its amplitude is:

$$F_0 = \sqrt{(kh_0)^2 + (c\omega h_0)^2}\ . \quad (2)$$

The free radius of the wheel is:

$$r_0 = \left(H + \frac{D}{2}\right) \cdot 25.4 \cdot \frac{1}{1000}, \quad (3)$$

where r_0 – free radius, m;
H – height of the tire, inch;
D – inner diameter of the rim, inch.

Deformation of the tire is:

$$\delta = (0.07 \div 0.065) r_0\ . \quad (4)$$

and its elastic constant is:

$$k = \frac{m}{2\delta} 9.81, \quad (5)$$

where k – elastic constant, $N \cdot m^{-1}$;
m=m_f, for the front wheel of the tractor;
m=m_s, for the rear wheel of the tractor.

In order to protect the vehicle and people, it is of interest that the force is transmitted to the casing (F_1) by means of the suspension system [4; 5].

The maximum transmitted through the spring and damper is:

$$F_1 = \left[kz + c\frac{dz}{dt} \right]_{\max} . \tag{6}$$

The coefficient of transmissibility is:

$$C_T = \sqrt{\frac{1 + 4\left(\frac{c}{c_0}\right)^2 \left(\frac{\omega}{p}\right)^2}{\left[1 - \left(\frac{\omega}{p}\right)^2\right]^2 + 4\left(\frac{c}{c_0}\right)^2 \left(\frac{\omega}{p}\right)^2}} . \tag{7}$$

The maximum force that can be sent to the fixed element can be greater than, equal to or less than the amplitude F_0 of the disturbing force, as $C_T > 1, C_T = 1$ or $C_T < 1$ [6; 7].

Based on the presented mathematical model, a modeling program of the driving or driven wheel of the tractor was developed in MathCAD [8].

Modeling of the tractor driving wheel

By help of the modeling program there were two driving wheels used at the U-650 tractor analyzed:

- a driving wheel with tires made in Romania;
- a driving wheel with GoodYear tires.

For each driving wheel, for the pressure of 1.2 bars and the load of 12000 N, there were the surface of contact with the ground, free wheel radius, radial deformation and lateral deformation measured [9]. The results are presented in Table 3.

Table 3

Characteristics of the studied driving wheels

Tire	Pressure, bar	Load, N	Support surface, cm²	Free radius, m	Radial strain		Lateral strain	
					mm	%	mm	%
16.9 – 38 Romania	1.2	12000	1470	0.838	33.2	3.96	37	8.5
16.9 – 38 GoodYear	1.2	12000	1365	0.838	27.3	3.25	12	2.8

The experimental data presented in Table 3 show that the area of contact between the wheel and the ground, as measured by the planimetry, is greater for the wheel produced in Romania. Also, the radial and lateral deformations are higher for the GoodYear wheel [10].

Elastic constants and dumping factors for the two driving wheels are:

- Romanian driving wheel: k=350700 N·m^{-1}; c=8000;
- GoodYear driving wheel: k=427300 N·m^{-1}; c=8827.

The program was run for slow and fast speeds of the U-650 tractor, and for two types of rolling paths: farmland and country road [8].

The tractor speeds are:

- slow speeds:

v_1=2.58 km·h^{-1}, v_2=4.16 km·h^{-1}, v_3=5.78 km·h^{-1}, v_4=7.68 km·h^{-1}, v_5=18.18 km·h^{-1};

- fast speeds:

v_1=3.83 km·h^{-1}, v_2=6.17 km·h^{-1}, v_3=8.56 km·h^{-1}, v_4=11.38 km·h^{-1}, v_5=26.94 km·h^{-1}.

The characteristics of the agricultural land are:

- irregularities height h_0=0.025 m;

- irregularities length. l=0.208 m.

The charts of the running path profile are obtained for slow and fast speeds of the tractor. There are also obtained charts for the driving wheel oscillations (for the two types of wheels and driving paths).

Below is presented the graph obtained from a comparison of the oscillations of the two driving wheel types when the tractor is moving on a country road [8].

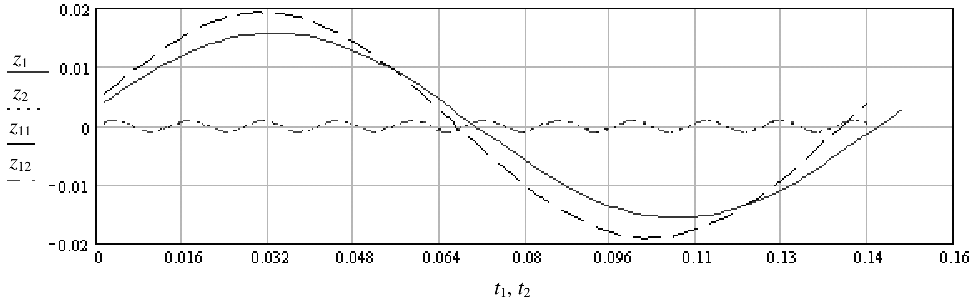

Fig. 2. **Comparison of oscillations for the studied tires when moving on country road**

In the case of movement of the driving wheels on the country road with fast speeds of the tractor, the amplitude of the oscillations of the driving wheel with the Romanian tire (z_1 at minimum speed, z_2 at maximum speed) for the minimum speed is less than the oscillation amplitude of the GoodYear wheel (z_{11} at the minimum speed and z_{12} at maximum speed). At other speeds, the amplitude of the oscillations is very close to each other. Figure 2 shows the oscillation of the two types of wheels when moving on the country road, for minimum respectively maximum wheel velocity (v_{min}=2.58 km·h^{-1}, v_{max}=26.94 km·h^{-1}).

Figure 3 shows the variation of the amplification factor (B) for the driving wheel with the tire manufactured in Romania and (B_1) for the driving wheel with the GoodYear tire when moving on the country road.

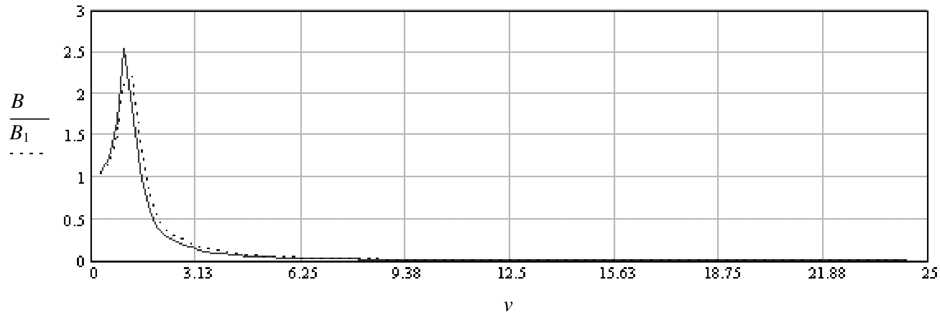

Fig. 3. **Variation of amplification factor depending on speed, for two driving wheels (country road)**

The maximum amount of the amplification factor is obtained for the minimum speed (B=2.6 for the wheel with the Romanian tire and B_1=2.2 for the GoodYear), and for the other speeds the values are very close to each other. The amplification factor in this case is very similar to the factor of amplification in the case of travel on farmland.

Modeling of the tractor driven wheel

The driven wheel for which the modeling program was run has the following characteristics:

- wheel height H=6″;
- diameter of the rim D=16″;
- elastic constant of the tire k=257900 N·m^{-1};
- damping constant of the tire c=1050 Ns·m^{-1}.

The charts are obtained for oscillatory movement of the driven wheel, for slow and fast speeds of the tractor moving on two types of land.

The program generates charts which allow comparing the oscillations of the driven and the driving wheels when they are moving on two types of roads, and a chart useful to compare the amplification factor of the two types of tires running on both types of roads.

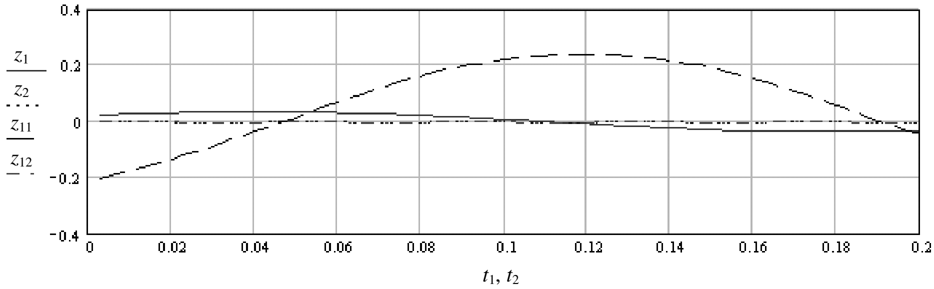

Fig. 4. **Oscillations of driving wheel (z_1 and z_2) and driven wheel (z_{11} and z_{12}) when moving on agricultural land**

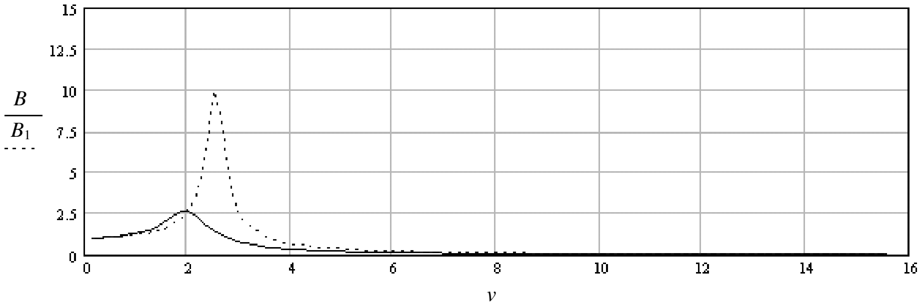

Fig. 5. **Amplification factors of the driving wheel (*B*) and driven wheel (B_1) when moving on agricultural land**

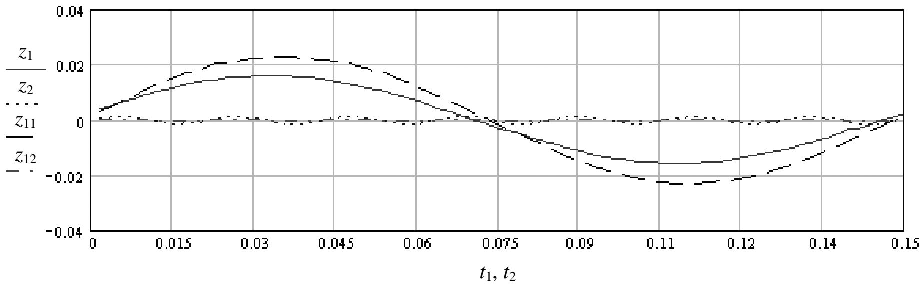

Fig. 6. **Oscillations of driving wheel (z_1 and z_2) and driven wheel (z_{11} and z_{12}) when moving on country road**

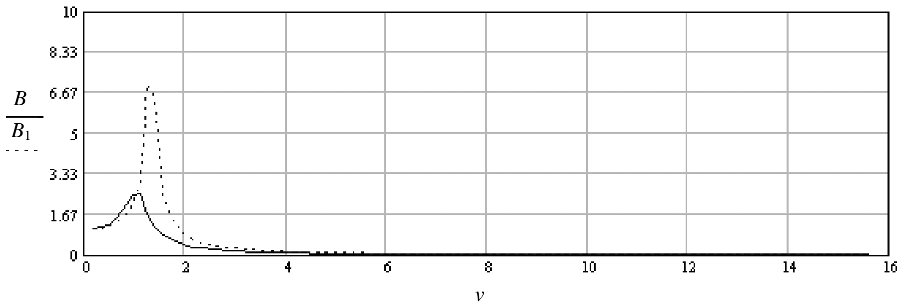

Fig. 7. **Amplification factors of driving wheel (*B*) and driven wheel (B_1) when moving on country road**

Conclusions

1. The program running the mathematical model of the tractor wheel allows the following operations: tracing the land profile for the five speeds of the tractor (slow or fast range); calculus of the elastic constants of the tire; determination of the amplitude of disturbing; oscillatory

movement of the wheel for each speed of travel; calculus of the amplification factor and the coefficient of transmissibility.

2. The parameters of the oscillatory motion for two driving wheels (one equipped with a tire made in Romania and the other one with a GoodYear tire) and for a driven wheel, all used on the U-650 tractor, were determined.
3. The oscillatory movement of the driving wheels has much higher amplitude at minimum speed than at other speeds, for both types of land where the tests were made.
4. The magnitude of the driving wheel with the tire manufactured in Romania is lower than the amplitude of the driving wheel equipped with the GoodYear tire when the movement is done on farm land, regardless of the speed range (slow/fast). The differences are obvious at minimum speeds.
5. The amplification factor of the driving wheel with the Romanian tire is less than the one with the GoodYear tire.
6. The oscillation amplitude of the driving wheel with the Romanian tire is lower than that of the driving wheel with the GoodYear tire, but it is much closer when moving on the country road than on farmland, at minimum speeds of displacement.
7. The oscillation amplitude of the driven wheel when moving on the country road is smaller than in the case of moving on farmland.
8. The amplification factor of the driven wheel is approximately four times greater when moving on agricultural land and almost three times higher when moving on the country road, at low speeds.
9. The oscillation amplitude values of all the wheels tested on the model with one degree of freedom will be considered as indicative, taking into consideration that the oscillatory movement of these wheels cannot be absolutely identical with the real movement due to the use of a very much simplified model.

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