TEKA Kom. Mot. Energ. Roln., 2006, 6, 29–33

MODELING OF DYNAMIC FORCES OF A TRACTOR AND THREE-POINT HITCHED IMPLEMENT IN THE MATLAB-SIMULINK PROGRAM ENVIRONMENT[1]

Konstanty Juziuczuk, Zbigniew Kamiński

Departament of Automotive Vehicles, Białystok University of Technology

Summmary. The system of a tractor with a hitched implement (THI) has been modeled in the MATLAB-SIMULINK program with the help of a mathematical system model. The exemplary results of simulative explorations of dynamic loads of the aggregate wheels are presented.

Key words: tractor, stability, steerability

INTRODUCTION

Safe usage of units, especially those with three-point hitched implements (THI) on the back is conditioned first of all by: a mutual fitting of the tractor and tool from the point of view of the lift capacity, the tractor's stability maintenance after the tool's rise, stability and controllability maintenance of tractor-implement aggregate while maneuvering on the field and transportation crossing. The execution of the latter condition has a particular importance for the safety of road traffic and the providing of the safe conditions of work for the instrument operator. The basic criterion of stability used in practice is the requirement of maintenance of defined value of static load R_p of tractor aggregate front wheels, for inst. $R_p \geq (0.15 \div 0.25) G_a$ [Kuczewski 1968], $R_p \geq (G_c \cdot L_u)/L_{12}$ [Meyer 1956], $R_p \geq (G_c \cdot L_c \cdot k)/L_{12}$ [Mertins and Ulrich 1978], where: G_c – weight of tractor; G_a – weight of tractor aggregate; L_u – conditioned distance of mass center from back axel wheels of tractor, L_u = 0.25 m; L_{12} – axel base of tractor; L_c – distance of mass center from back axel wheels of tractor; k = (0.375÷0.565) – empiric coefficient, its values presented above are used for tractors exploited on mountain site.

Since the task of the definition of static load of front wheels of aggregate is simply solved on the basis of static, the estimation of the connected dynamic loads requires the application of numeric simulation methods. Using classical mathematical model of tractor suspension, its block scheme has been constructed in the program Matlab-Simulink. The dynamic system obtained in this way has its input. Through the input the motoring speed and the function which describes the road roughness under the wheels are set. The output is defined in the form of linear and angle displacements of aggregate and road groundwork reaction on the wheels.

[1] The work was sponsored by Rector's project W/WM/7/03

A MATHEMATICAL MODEL OF TRACTOR OSCILLATION

For the description of dynamic loads the classic flat mechanical system was used [Chodkowski 1982]. It was assumed, that the vehicle moves rectilinearly on the road with the same road roughness under the wheels of both left and right side of the aggregate, and the aggregate mass is distributed symmetrically concerning its central plane. Besides, it was assumed that the joint of the tractor and hitched implement on (THI) is inflexible. Therefore, the aggregate is regarded as the stiff body. The model of aggregate composed from springing mass m_a with the center in S point and inertia moment I_a is shown in Fig. 1.

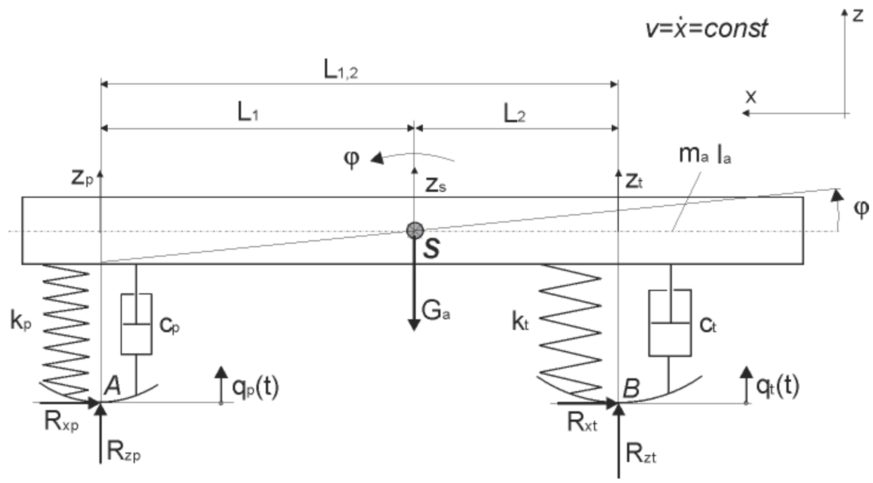

Fig. 1. The physical model of the stiff joint of the aggregate: tractor-hitched-implement

At the same time it is assumed that in the composition of the springing mass the masses of vehicle wheels are included. It appears from the absence of the classic mounting of the vehicle wheels. The springing mass is connected with a weightless tire which is characterized by both stiffness coefficients of tire of front and back wheels k_p and k_t and coefficient of tire damping c_p and c_t. The model location in coordinates x, z define: rotation angle φ, vertical displacement z_s of mass m_a center, vertical displacements z_p and z_t in the plane of front and back axels.

We can obtain the following differential equation from the equilibrium condition of forces projections on 0z axis and from the equilibrium condition of moments of forces concerning the axis which goes through the mass center S and orthogonal to 0xz plane:

$$\begin{aligned} m_a \cdot \ddot{z}_s &= R_{zp} + R_{zt} - G_a \\ I_a \cdot \ddot{\varphi} &= -R_{zp} \cdot L_1 + R_{zt} \cdot L_2 \end{aligned} \qquad (1)$$

where:

L_1, L_2 – are the distances of mass center from the wheels of front and back axels correspondently;

G_a – force of gravity of the aggregate.

Dynamic reactions of the road groundwork on the wheels of front R_{zp} and back R_{zt} axels are described by the dependences:

$$R_{zp} = 2k_p(q_p - z_p) + 2c_p(\dot{q}_p - \dot{z}_p)$$
$$R_{zt} = 2k_t(q_t - z_t) + 2c_t(\dot{q}_t - \dot{z}_t) \tag{2}$$

where:

q_p, q_t – kinematical inputs on the wheels of front and back axels.

There are the following dependences between displacement z_s of mass center of aggregate, rotation angle φ and displacements z_p, z_t of vehicle axels:

$$z_p = z_s - L_1 \cdot \varphi \qquad z_t = z_s + L_2 \cdot \varphi$$
$$z_s = \frac{z_p \cdot L_2 + z_t \cdot L_1}{L_{1,2}} \qquad \varphi = \frac{z_t - z_p}{L_{1,2}} \tag{3}$$

After the substitution of the expressions (2) and (3) to (1) we obtain the equations of the aggregate dynamic which are the base for elaboration of Matlab-Simulink model (Fig. 2). Each equation is represented by one of the two main lines in the subsystem's „suspension". The main lines of the model correspond to the two degrees of freedom of the aggregate and are coupled. Transport Delay block realizes the input delay of back axel according to driving velocity v and axel base of tractor.

The worked out model allows for the choice of one of the three input signals which represent the obstacle overcome by the aggregate. These are: sinusoidal hump of the given height and base width, step the of given height and irregularity of stochastic character (coefficient k_o is the measure of road quality, and coefficient $w_o = 10/v$ depends on the driving velocity v).

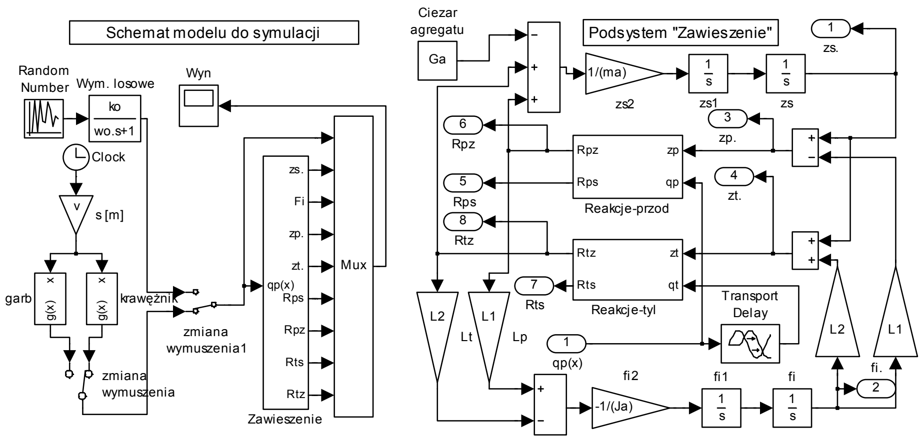

Fig. 2. The model scheme for simulation and structural scheme of „suspension" subsystem

The results of simulation are obtained on the output of „suspension" subsystem: time runs of vertical and angle displacements of aggregate body and dynamic reactions of road groundwork.

EXEMPLARY RESULTS OF SIMULATION EXPLORATIONS

For a simulation exploration the tractor of 50 kW power, axel base L_{12} = 2.15 m and own mass of m_c = 2800 kg was chosen. The following parameters of tire were accepted: $k_p = 2.1 \cdot 10^5$ N/m, $k_t = 2.25 \cdot 10^5$ N/m, $c_p = 1.2 \cdot 10^3$ Ns/m i $c_t = 2.45 \cdot 10^3$ Ns/m. The exploration was based on the definition of time runs of longitudinal vibrations and wheels load of aggregate while driving with various velocity through obstacles. Runge–Kutta method was used in the simulation accepting 0.0001 as minimal integration step, 0.01 as maximal integration step and tolerance equal to 10^{-6}. Exemplary exploration results for unloaded tractor and aggregate tractor-mounting-tool are shown in Fig. 3.

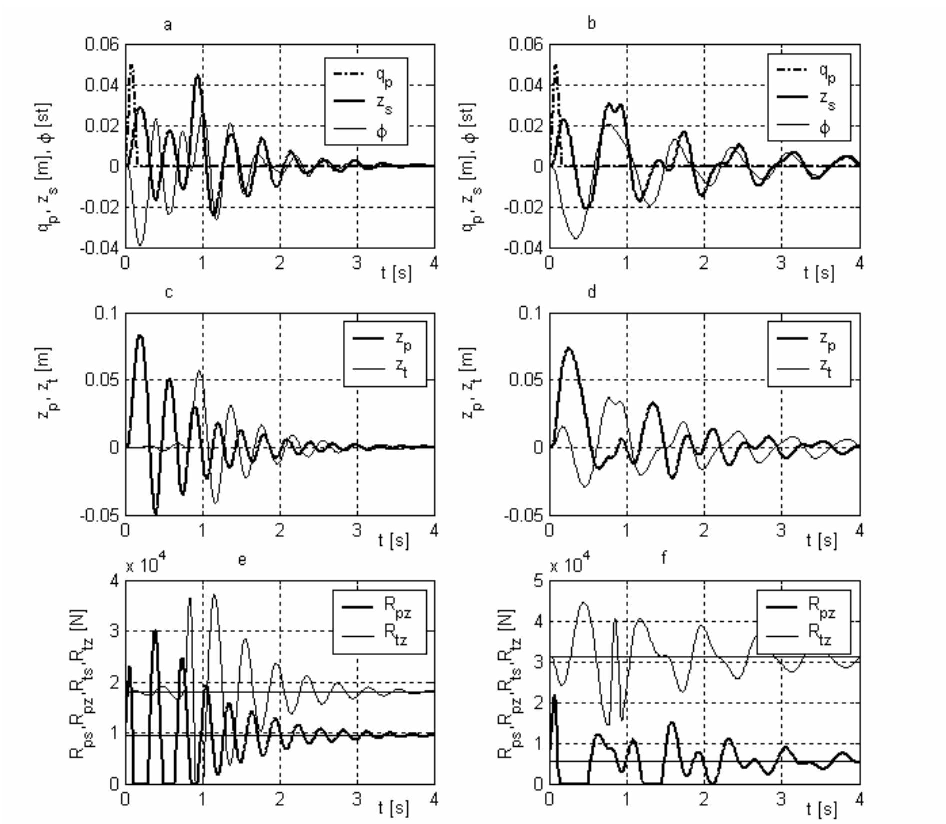

Fig. 3. Exemplary results of aggregate explorations while passing the sinusoidal hump of 0.05 m height and 0.5 m base width with the velocity of 10 km/h: a, c, e – for unloaded tractor (m_c = 2800 kg, I_a = 2800 kg·m^2, L_2 = 0.74 m); b,d,f – for aggregate with hithed implement (m_c = 3740 kg, I_a = 10180 kg·m^2, L_2 = 0.32 m)

In the case of passing of unloaded tractor through sinusoidal obstacle the vertical displacement of front is bigger than in the case of aggregate passing. The obvious detachment of front axel wheels from road surface takes place. That means that the timely loss of tractor steerability appears. Reduction of vertical displacements comes quicker with relation to the aggregate passing time. Reaction value on front axel wheels comes under much more considerable oscillations and is characterized by a higher frequency than in the case of aggregate.

CONCLUSIONS

Static methods of the detection of road groundwork reactions impact on the wheels of a tractor's front axel are only of an exemplary character. The methods don't take into account the dynamics of the tractor and its hitched implement as a physical system.

The motion stability modeling in a system tractor-implement – the system with different constructions – with elements which work in different conditions requires to take into account the spectrum of loads of a tractor with a three-point mounting implement (THI). The loads are the results of kinematical inputs which depend on roads profiles.

The presented in the work exemplary results of behaviour simulation in a tractor front axel under an influence of sinusoidal inputs are to be regarded as the contribution to the following explorations of a widely understood stability of the tractor-implement system. Further research on the defining of an influence of mass parameters of a hitched implement and front ballast on the wheels loads of the aggregate while passing through different obstacles will be conducted after the verification of the described mathematical model.

REFERENCES

Chodkowski A.W. 1982: Badania modelowe pojazdów gąsienicowych i kołowych. WKiŁ, Warszawa.
Kuczewski J. 1968: Podstawy eksploatacji agregatów rolniczych. PWRiL, Warszawa.
Meyer H. 1956: Zur Problematik des Sattelanhangers fur Ackerschlepper. Landt. Forschung Bd. 6, 39–42.
Von Mertins K.H., A.Ulrich A. 1978: Zur Frage der Lenksicherheit von Ackerschleppern mit Anbaugeraten bei StraBenfahrt. Grundl. Landtechnik Bd. 28, 3.