SIMULATION OF PRESSURE OSCILLATION IN HYDRAULIC HITCH-SYSTEM

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Abstract. The paper presents simulation results of tractor movement with attached disc harrow over rough surface. Working Model software is used for simulation. Hitch-system cylinder is replaced as coupler with spring and damper characteristic in model. Dynamic force on coupler is obtained as simulation result and depending on it hydraulic pressure in hitch-system cylinder had been calculated. Simulation results are evaluated on basis of experimental investigations.

Key words: tractor hitch system, pressure oscillation simulation.

Introduction

During tractor movement, with attached to hitch-system working equipment (plough, harrow), over rough road surfaces oscillation of machine take place. These oscillations are a reason of pressure pulsations in hydraulic hitch-system.

Pressure pulse reduction in tractor hitch-system is important for increasing of system components lifetime. Pressure oscillations damping in the tractor hydraulic hitch-system can reduce overall system oscillations and improve the driving control.

Modern tractor linkage system is fitted with oscillation damper, with reduces the hydraulic hitch-system pressure oscillations. Simulations of tractor hydraulic system oscillation enable determination of hydraulic system stiffness and damping parameters for minimizing amplitude of pressure pulsations.

Working Model software let to create dynamic model for tractor vertical oscillations and simulate movement with different speed and road roughness values.

Materials and methods

For evolution of Working Model simulation results preliminary experiments on tractor movement over artificial roughness test road had been carried out.

Using the Working Model software [1] is necessary to determinate the hydraulic system pressure in tractor (Class Ares 557 ATX) hydraulic hitch-system hydro cylinder depending on the attached equipment weight, road roughness and tractor speed.

In Working Model software dynamic model the same parameters of tractor and attached equipment [2-5] weight, road roughness and movement speed as in experimental investigation had been used. Oil volume stiffness for tractor hydraulic system was calculated [6]. Simulation model (see Figure 1) is used in the side-view. The parameters of hydraulic cylinder and tyres are entered two times larger in simulation model.

Sinusoid function is used for the road roughness description in model [7]:

$$y = a \cdot \sin(\omega_f \cdot t), \quad (1)$$

where a – roughness amplitude, m;
ω_f – forced oscillation frequency, s^{-1};
t – time, s.

Road roughness amplitude is constant value $a = 0.05$ m. Frequency forced oscillation of is dependent on tractor driving speed and road roughness step (2). Road roughness step s = 2 m is equal with the step of experimental road.

$$\omega_f = \frac{v \cdot 2\pi}{s}, \quad (2)$$

where v – tractor drive speed, $m \cdot s^{-1}$;
s – road roughness step, m.

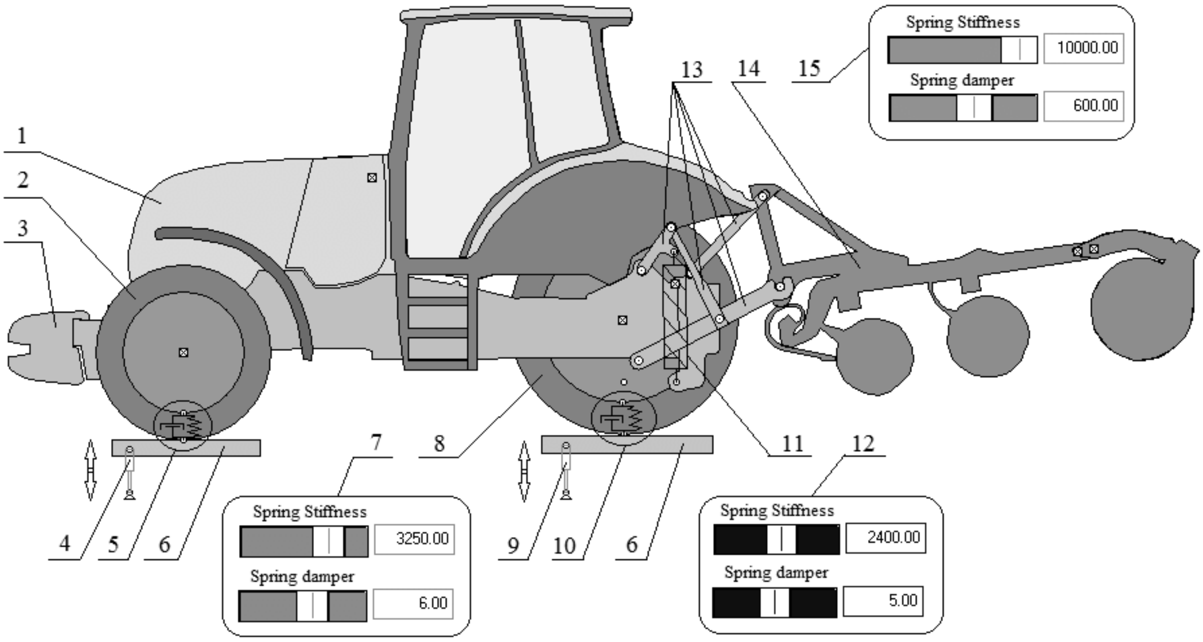

Fig. 1. **Tractor model in Working Model software:**
1 – tractor Class Ares 557 ATX, 2 – tractor front tyres (13.6R28), 3 – front weight, 4 – front actuator, 5 – front tyres (characterization by spring and damper), 6 – road roughness, 7 – front tyres control units, 8 – tractor rear tyres (16.9R38), 9 – rear actuator, 10 – rear tyres (characterization by spring and damper), 11 – hydraulic cylinder (characterization by spring and damper), 12 – rear tyres control units, 13 – tractor hitch-system, 14 – soil cultivator implements, 15 – hitch-system control units

Tractor wheelbase is $l_t = 2.564$ m. As the tractor wheelbase does not coincide with road roughness step, the time delay Δt between roughness impact on front wheels and rear wheels:

$$\Delta t = \frac{\Delta l}{v}, \tag{3}$$

where Δt – time delay, s;
Δl – step difference between tractor wheelbase and road roughness, m.
Δl is calculated:

$$\Delta l = l_t - s\,. \tag{4}$$

Function of road roughness surface in Working Model program is assured with actuators 4 and 9 (see Figure 1). Actuator functions of the front and rear wheels are given in program by equation (5), where y_1 is the function of front wheel oscillations, but y_2 is for back wheels.

$$\begin{aligned} y_1 &= b + if\,(a\cdot\sin(\omega_f\cdot(t+\Delta t)) < 0{,}0{,}(a\cdot\sin(\omega_f\cdot(t+\Delta t)))) \\ y_2 &= b + if\,(a\cdot\sin(\omega_f\cdot t) < 0{,}0{,}(a\cdot\sin(\omega_f\cdot t))) \end{aligned} \tag{5}$$

where b – initial length of actuator, m.

If the function $y = a\cdot\sin(\omega_f\, t) < 0$, then the function value is 0, but if $a\cdot\sin(\omega_f\, t) > 0$, then the function value is $y = a\cdot\sin(\omega_f\, t)$. Road roughness simulation is showed in Figure 2.

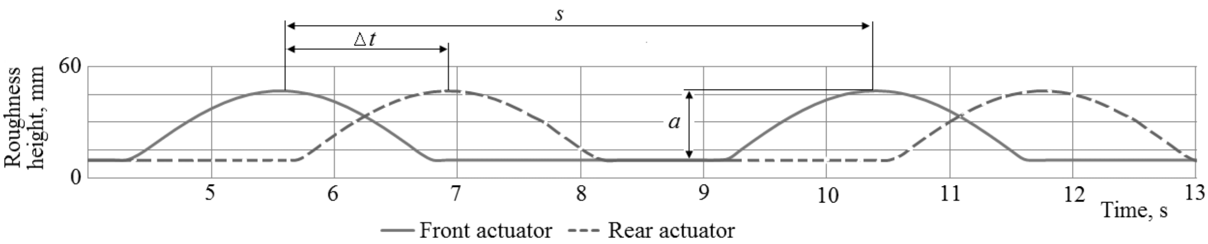

Fig. 2. **Road roughness:**
Δt – oscillation time delay, s – road roughness step, a – road roughness amplitude

Road surface and tractor movement descriptive values are used in simulation and given in Table 1.

Table 1

The input parameter of simulation

Velocity v, $m \cdot s^{-1}$	**Angular frequency ω_f, s^{-1}**	**Oscillation time delay Δt, s**
0.83	2.62	0.677
1.33	4.19	0.423
1.50	4.71	0.376
1.78	5.59	0.317
2.17	6.81	0.260
2.50	7.85	0.226
3.11	9.77	0.181
3.42	10.73	0.165
3.81	11.96	0.150

In the model hitch-system hydraulic cylinder 11 (Figure 1) is created and described with spring and damper characteristic. The spring and damper are characterized by stiffness and damping coefficients. Tractor hitch-system hydraulic cylinder parameters are changed with control button 12 (Figure 1). Approximate spring stiffness coefficient can be calculated from formula (6).

$$c = \frac{F}{x}, \tag{6}$$

where c – spring stiffness coefficient, $N \cdot m^{-1}$;
F – force, N;
x – displacement, m.

The force F value is obtained from experiment results (F = 328564 N). Displacement x is equal to the hitch-system hydraulic cylinder displacement at pressure pulse. It can be calculated [6] from volume change ΔV in hydraulic cylinder from equation:

$$\frac{1}{E} = \frac{\Delta V}{\Delta p \cdot V_0}, \tag{7}$$

where E – liquid modulus of elasticity, $N \cdot m^{-2}$;
ΔV – volume change in the size of the pressure changes, m^3;
V_0 – initial volume of liquid at atmospheric pressure, m^3;
Δp – pressure change, $N \cdot m^{-2}$.

Values of pressure changes is determinated from experimental tests $\Delta p = 57 \cdot 10^5$ $N \cdot m^{-2}$. Oil modulus of elasticity $E = 729 \cdot 10^6$ $N \cdot m^{-2}$. Initial fluid volume in hydraulic hitch-system cylinder at atmospheric pressure is calculated:

$$V_0 = \frac{\pi \cdot d^2 \cdot h}{4}, \tag{8}$$

where d – hydraulic cylinder diameter, m;
h – hydraulic cylinder stroke, m.

From tractor Class Ares hydraulic hitch-system cylinder determinate sizes d = 0.075m and h = 0.23m. Displacement x is calculate from formula (9).

$$x = \frac{4\Delta V}{\pi \cdot d^2}. \tag{9}$$

The approximate stiffness coefficient can be calculated after the displacement x determination according formula (6). Input constant parameters are given in Table 2.

Table 2

Parameters of simulation

Road roughness step s, m	**Road roughness amplitude a, m**	**Tyre stiffness coefficient c, N·m^{-1}**		**Tyre damping coefficient b, N·s·m^{-1}**		**Hitch-system parameters**	
		Front	**Rear**	**Front**	**Rear**	**Stiffness coefficient, N·m^{-1}**	**Damping coefficient, N·s·m^{-1}**
2	0.05	680000	850000	16000	30000	82140750	5000000

Tractor tyre parameters are dependent on tire pressure. Decreasing tire pressure from 1.2 to 0.8 bar, maximum average values of pressure in hydraulic hitch-system during oscillations are decreased.

Force is measured when tractor model hydraulic hitch-system hydraulic cylinder oscillation is simulated with Working Model software. Corresponding pressure is calculated:

$$p = \frac{F_u}{A}, \tag{10}$$

where p – pressure, Pa;
F_u –hydraulic hitch-system hydro cylinder force, N;
A – area of hydraulic cylinder, m^2.

With constant spring stiffness coefficient, reducing the damping coefficient, the force of hydraulic hitch-system hydro cylinder decreases. Changing the damping coefficient values from 4-6.5 N·s·m^{-1} pressure values similar to experimental values are obtained. Working Model tractor simulation model checking on the basis of experimental investigations let improve it coincidence with real machine aggregate.

Results and discussion

Changing the tractor hydraulic hitch-system (stiffness and damping) parameters and speeds from 3-14 km·h^{-1} there are obtained the different pressure values in linkage cylinder. The experimentally obtained hydraulic hitch-system pressure values and the Working Model program simulation pressure values are shown in Figure 3. The maximum pressure oscillation amplitude is observed at the speed 7.8 km·h^{-1}, and reaches 188 bar in experiments, but at the same speed reaches 182 bar in simulation results. The differences between simulation and experimental investigation results vary with in 2-10 %.

These differences are caused with some inconsistency for stiffness of tyres in simulation model and can be eliminated. Therefore Working Model simulation for tractor hydraulic hitch-system can be recommended for investigation of possibility to reduce amplitude of pressure pulsations by changing parameters of hydraulic system.

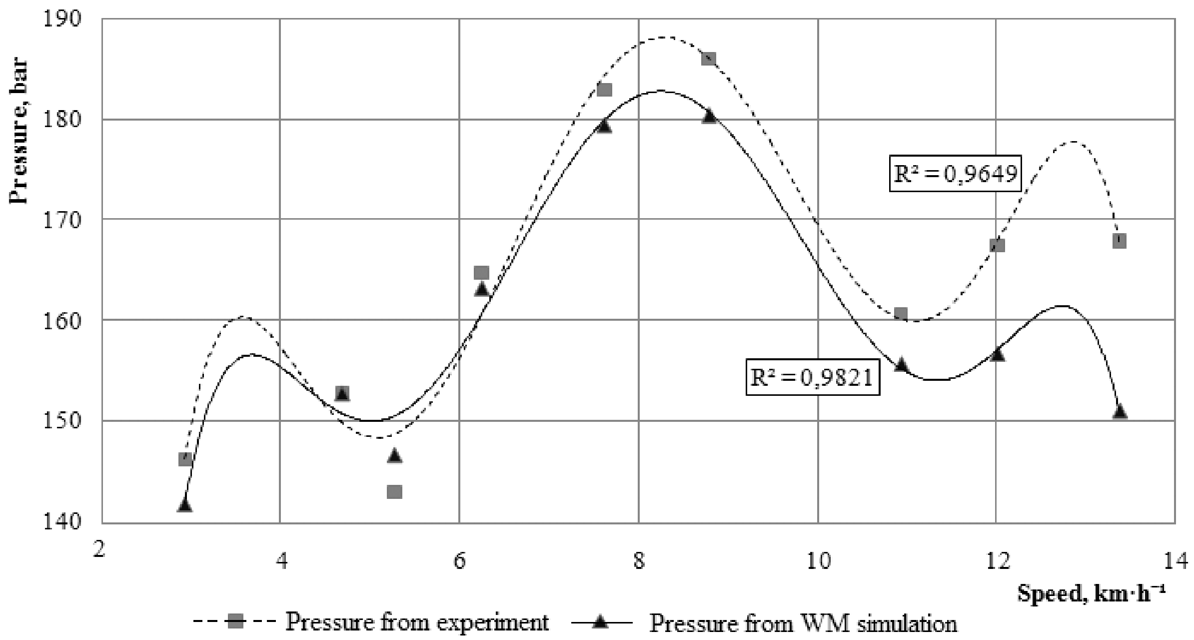

Fig. 3. **Pressure in tractor hydraulic hitch-system of hydraulic cylinder**

Conclusions

1. Working Model software lets to create dynamic model for tractor vertical oscillations and simulate movement with different speed and road roughness values.
2. Working Model tractor simulation model checking on the basis of experimental investigations let improve it coincidence with real machine aggregate.
3. The maximum pressure oscillation amplitude is observed at the speed 7.8 $km \cdot h^{-1}$, and reaches 188 bar in experiments, but at the same speed reaches 182 bar in simulation results.
4. The differences between simulation and experimental investigation results vary within 2-10 %.
5. Working Model simulation for tractor hydraulic hitch-system can be recommended for investigation of possibility to reduce amplitude of pressure pulsations by changing parameters of hydraulic system.

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