ISSN 1392-1134
Lietuvos žemės ūkio universiteto mokslo darbai 2010, 42 (2-3), 22 – 31
Research papers of Lithuanian University of Agriculture, 2010, vol 42, no 2-3, 22 – 31

PRESSURE OSCILLATION IN HYDRAULIC HITCH-SYSTEM DURING IMPLEMENT TRANSPORT

SLĖGIO SVYRAVIMAI HIDRAULINIO KELTUVO SISTEMOJE TRANSPORTO REŽIME

Janis Laceklis – Bertmanis, Aivars Kakitis, Eriks Kronbergs, Edgars Repsa and Mareks Smits

Latvia University of Agriculture, Institute of Mechanics,
E-mail: Janis.Laceklis@llu.lv

Gauta 2010-05-23, pateikta spaudai 2010-09-06

This paper presents results of pressure oscillation investigation in tractor Claas Ares ATX 557 hydraulic hitch-system, loaded with disc harrow, during the motion around artificial roughness test road. During experiments oscillation at the different drive speed, tires pressure and hitch-system oscillation damping (turned on or off) were investigated. Tractor hydraulic hitch-system was equipped with pressure sensor and data processing software. Results of experiments present maximum pressure peak 188 bar in tractor hydraulic system, if not used hydraulic hitch-system oscillation damping system at driving speed 8 km h^{-1}, and if used hydraulic hitch-system oscillation damping system pressure peak reduced to value 170 bar. Simulation of tractor movement with attached disc harrow over rough surface with Working Model software was used. Hitch-system cylinders were replaced as coupler with spring and damper characteristic in model. Dynamic force on coupler was obtained as simulation result and depending on it hydraulic pressure in hitch-system cylinder had been calculated. Simulation results were evaluated on basis of experimental investigations. Reducing of hydraulic cylinder stiffness value let to reduce pressure value to 168 bar at driving speed 8 km h^{-1} during simulation.

Tractor hitch-system, pressure oscillation.

Introduction

During tractor movement, with attached to hitch-system working equipment (plough, harrow), over rough road surfaces vertical oscillations of machine take place. These oscillations are a reason of pressure pulsations in hydraulic hitch-system and reduce the service life of hydraulic system components, especially the lifetime of hydraulic hoses.

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.

Simulation of tractor hydraulic system oscillation enables 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.

The main task of simulation experiment is to reduce the tractor Claas Area 557 ATX hitch-system hydraulic pressure pulse values changing the hydro cylinder stiffness and damping parameters.

Materials and methods

For evaluation of Working Model simulation results preliminary experiments on tractor movement over artificial roughness test road had been carried out. In experiment tractor Claas Area 557 ATX was used. The tractor with LEMKEN short disk harrow and LEMKEN rubber rings roller was fitted [1, 2].

Using the Working Model software [3] 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.

Therefore, in experiment the tractor hydraulic hitch-system was equipped with pressure oscillation sensor Wika Transmitter ECO-1. The sensor was chosen such that own oscillation frequency was 10 times higher than frequency of measured pressure changes [4]. For data acquisition and processing software offered by company Pico Technology was used [5]. Using Wika Transmitter ECO-1 and universal data collection and processing device PicoLog the hydraulic pressure oscillation in tractor hydraulic hitch-system was measured.

In order to study the dynamic oscillation of tractor hydraulic hitch-system in experiments road with artificial roughness was used (see Fig. 1). Road roughness was established according to rural conditions. Total road length was 24 meters which was divided into 12 equal parts by 2 meters each, respectively. Road roughness was constructed from wood planks with dimensions 150 x 50 x 1000 mm. Planks are connected with steel angle shaped bars 40 x 40 x 3 mm by screw-bolts. Roughness columns were placed in two parallel rows with 1.8 m distance on asphalt road surface.

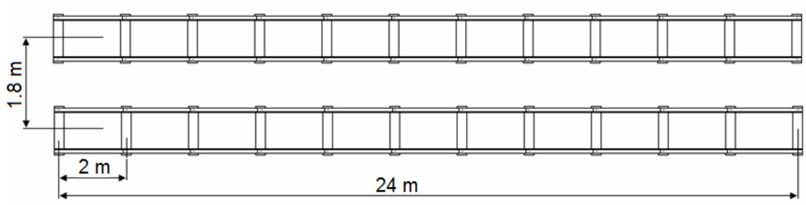

Fig. 1. Artificial roughness test road
1 pav. Dirbtiniai bandymo kelio nelygumai

Road roughness amplitude was constant value a = 0.05 m. Frequency of forced oscillations in dependence on tractor driving speed and road roughness step s = 2 m can be found:

$$\omega_f = \frac{v \cdot 2\pi}{s}, \qquad (1)$$

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

In way of changing tractor hydraulic hitch-system oscillation damping position (switch on or off) and driving speed from 3 – 14 km h^{-1} various hydraulic hitch-system oscillation characteristics are acquired, which may occur the pressure pulse in hydraulic system. The maximum pressure oscillation amplitude was observed at driving speed of 8 km h^{-1} and it reached 188 bar. For hydraulic hitch-system longer service life it would be necessary to reduce the hydraulic pressure oscillation to a greater range and for this the Working Model simulation programme was used.

In Working Model software dynamic model the same parameters of tractor and attached equipment [6] weight, road roughness and movement speed as in experimental investigation had been used. Oil volume stiffness for tractor hydraulic system was calculated [7]. Simulation model (see Fig. 2) was used in the side-view. The parameters of hydraulic cylinder and tyres were entered two times larger in simulation model.

Tractor wheelbase was 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 exist:

$$\Delta t = \frac{\Delta l}{v}, \qquad (2)$$

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

Δl was calculated:

$$\Delta l = l_t - s. \qquad (3)$$

Function of road roughness surface in Working Model program was assured with actuators 4 and 9 (see Fig. 2). Actuator functions of the front and rear wheels was given in program by equation (4), where y_1 was the function of front wheel oscillations, but y_2 was for rear wheels.

$$y_1 = b + if\,(a \cdot \sin(\omega_f \cdot (t + \Delta t)) < 0{,}0,(a \cdot \sin(\omega_f \cdot (t + \Delta t))))$$
$$y_2 = b + if\,(a \cdot \sin(\omega_f \cdot t) < 0{,}0,(a \cdot \sin(\omega_f \cdot t))) \tag{4}$$

where b – initial length of actuator, m.

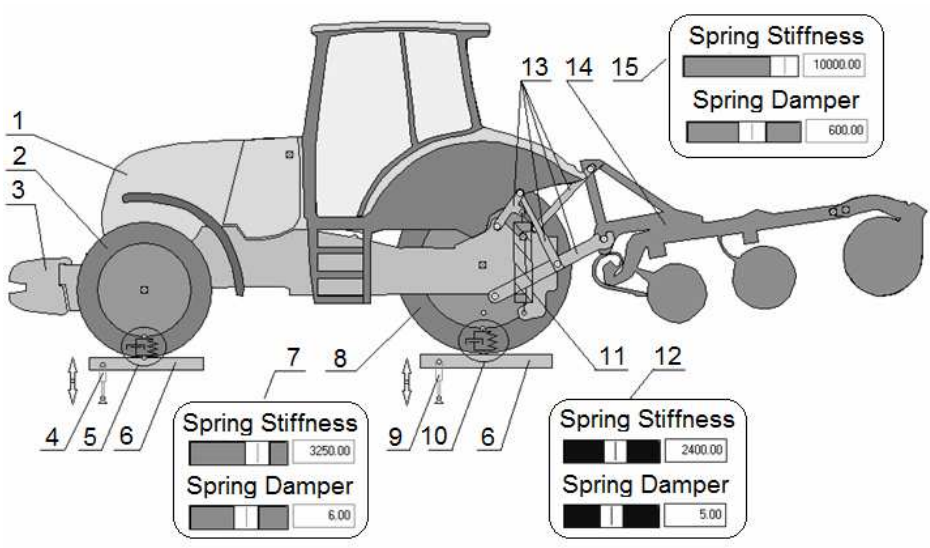

Fig. 2. Tractor model in Working Model software: 1 – tractor Class Ares 557 ATX, 2 – tractor front tyres (13.6R28), 3 – front weight, 4 – front actuator, 5 – front tyres (characterization by spring and damper), 6 – road roughness, 7 – front tyres control units, 8 – tractor rear tyres (16.9R38), 9 – rear 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
2 pav. Traktoriaus modelis: 1 – traktorius Claas Ares 557 ATX, 2 – traktoriaus priekinės padangos (13.6R28), 3 – priekinis svoris, 4 – priekinis vykdiklis, 5 – priekinės padangos (elastingumo ir dempferiavimo modulis), 6 – kelio nelygumai, 7 – priekinių padangų valdymo blokas, 8 – traktoriaus užpakalinės padangos (16.9R38), 9 – užpakalinis vykdiklis, 10 – užpakalinės padangos (elastingumo ir dempferiavimo modulis), 11 – hidraulinis cilindras (elastingumo ir dempferiavimo modulis), 12 – užpakalinių padangų valdymo blokas, 13 – traktoriaus keltuvas, 14 – kultivatorius, 15 – keltuvo valdymo blokas

If the function $y = a \cdot \sin(\omega_f \cdot t) < 0$, then the function value was 0, but if $y = a \cdot \sin(\omega_f \cdot t) > 0$, then the function value was $y = a \cdot \sin(\omega_f \cdot t)$. Road roughness simulation was showed in Fig. 3.

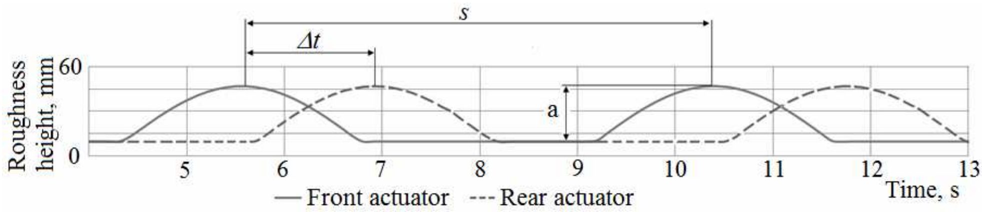

Fig. 3. Road roughness: Δt – oscillation time delay, s – road roughness step, a – road roughness amplitude

3 pav. Kelio nelygumai: $\Delta\ t$ – virpesių vėlinimo trukmė, s – kelio nelygumų žingsnis, a – kelio nelygumų amplitudė

In the model hitch-system hydraulic cylinder 11 (Fig. 2) was created and described with spring and damper characteristic. The spring and damper was characterized by stiffness and damping coefficients. Tractor hitch-system hydraulic cylinder parameters were changed with control button 12 (Fig. 2). Approximate spring stiffness coefficient can be calculated from formula (5).

$$k = \frac{F}{x}, \tag{5}$$

where k – spring stiffness coefficient, N m^{-1};
F – force, N;
x – displacement, m.

The force F value was obtained from experiment results (F = 328564N). Displacement x was equal to the hitch-system hydraulic cylinder displacement at pressure pulse. It can be calculated [8] from volume change ΔV in hydraulic cylinder from equation:

$$\frac{1}{E} = \frac{\Delta V}{\Delta p \cdot V_0}, \tag{6}$$

where E – liquid modulus of elasticity, N 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 m^{-2}.

Values of pressure changes was determinated from experimental tests Δp = 57·10^5 N m^{-2}. Oil modulus of elasticity E = 72·10^6 N m^{-2}. Initial fluid volume in hydraulic hitch-system cylinder at atmospheric pressure is calculated:

$$V_0 = \frac{\pi \cdot d^2 \cdot h}{4}, \qquad (7)$$

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

From tractor Class Ares hydraulic hitch-system cylinder determinate sizes d = 0.075 m and h = 0.23 m. Displacement x was calculate from formula (8).

$$x = \frac{4\Delta V}{\pi \cdot d^2}. \qquad (8)$$

The approximate stiffness coefficient can be calculated after the displacement x determination according formula (5). Input constant parameters were given in Table 1.

Table 1. Parameters of simulation.
1 lentelė. Modeliavimo parametrai.

Road roughness step s, m	Road roughness amplitude a, m	Tyre stiffness coefficient k, 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	560000	640000	10000	24000	50947368	2500000

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

$$p = \frac{F_u}{A}, \qquad (9)$$

where p – pressure, Pa;
F_u – hydraulic hitch-system hydro cylinder force, N;
A – area of hydraulic cylinders, 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 was obtained. Working Model tractor simulation model checking on the basis of experimental investigations let improve it coincidence with real machine aggregate.

Results and discussion

In Fig. 4 average values of hydraulic system pressure at different motion speeds and tire pressure was described. Under way with tractor along artificial roughness test road with air pressure in tires of 0.8 bar, what confirms to transportation regime of aggregate, and driving speed of 5 km h^{-1} (see Fig. 4) steerability of tractor was good and pressure in hydraulic hitch-system was in limits 130–150 bar.

Increasing driving speed step by step from 5 to 8 km h^{-1} pressure in hydraulic hitch-system increased and achieved 188 bar. The steerability of tractor became worse and it had been observed that front wheels had draw away from road surface.

Increasing driving speed step by step from 8 to 11 km h^{-1} pressure in hydraulic hitch-system had decreased to 148–158 bar and steerability of tractor has improved but exceeding driving speed over 13 km h^{-1} steerability had become worse.

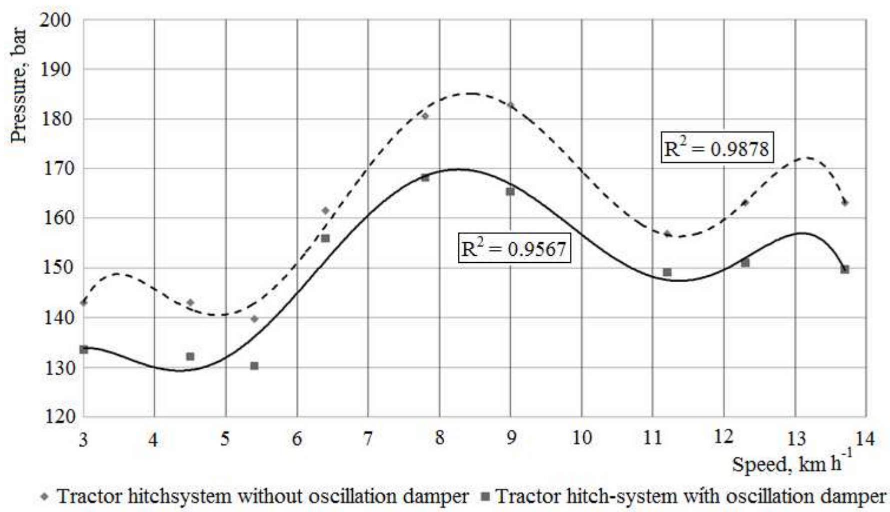

Fig. 4. Tractor hitch-system oscillation at different speed and at tire pressure 0.8 bar

4 pav. Traktorius hidraulinio keltuvo sistemos virpesiai esant skirtingiems greičiams ir slėgiui padangose 0,8 bar

Using the Working Model software the tractor hydraulic hitch-system hydro cylinder (stiffness and damping) parameters and driving speed from 3 - 14 km h^{-1} was simulated. The experimentally obtained hydraulic hitch-system pressure values and the Working Model program simulation pressure values are shown in Fig. 5. The maximum pressure oscillation amplitude was observed at the speed 8 km h^{-1}, and reaches 188 bar in experiments, but at the same speed reaches 182 bar in simulation results. Reducing of hydraulic cylinder stiffness value let to reduce pressure value to 168 bar at driving speed 8 km h^{-1} during simulation.

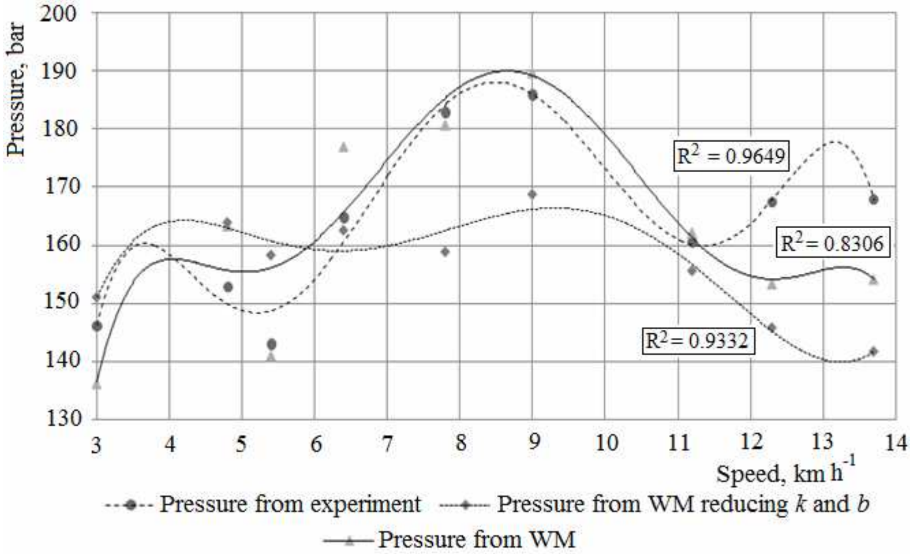

Fig. 5. Pressure in tractor hydraulic hitch-system of hydraulic cylinder
5 pav. Slėgis traktoriaus hidraulinio keltuvo cilindre

The differences between experimental and simulation results 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.

Conclusions

1. Oscillation of pressure can be reduced by exploitation of oscillation damper that can be established on instrument panel of tractor. If oscillation damper was not used, than at driving speed of 8 km h^{-1} pressure oscillation in hydraulic system reaches 188 bar but, when oscillation damper was used, pressure in hydraulic system decreases to 170 bar.
2. Working Model software let to create dynamic model for tractor vertical oscillations and simulate movement with different speed and road roughness values.
3. Tractor simulation model checking on the basis of experimental investigation results let improve it coincidence with real machine aggregate.
4. The maximum pressure oscillation amplitude was observed at the speed 8 km h^{-1}, and reaches 188 bar in experiments, but at the same speed reaches 182 bar in simulation results.

5. Reducing of hydraulic cylinder stiffness value let to reduce pressure value to 168 bar at driving speed 8 km h^{-1} during simulation.
6. 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.

Acknowledgement

Paper becomes written by financial support of European Structural Fund – Support for Realization of Doctoral Studies in Latvia University of Agriculture – realized by Project Department of Latvia University of Agriculture (contract no. 2009/0180/1DP/1.1.2.1.2/09/IPIA/VIAA/017).

References

1. LEMKEN GmbH & Co.KG [online]. Technical Data Compact Disc Harrow Heliodor, 2010 [cited March 25, 2010]. Available: http://lemken.com/appc/content_manager/page.php?ID=200741&dbc=d41c7cade764dc9bb388a723591737a9
2. LEMKEN GmbH & Co.KG [online]. Technical Data Rubber rings Rullers, 2010 [cited March 25, 2010]. Available: http://lemken.com/appc/_upload/2009_27/Walzen_de.pdf
3. MSC.Software Corporation. Working Model 2D software, User's Manual (2000).
4. Kaķītis A., Galiņš A., Leščevics P. (2008) Sensori un mērīšanas sistēmas. (Sensors and measuring systems) *Jelgava*, pp. 380-390. (in Latvian)
5. Kaķītis A. (2008) Neelektrisko lielumu elektriskā mērīšana un sensori: mācību līdzeklis. (Non-electric value electrical measuring and sensor: Study aid.) *Jelgava*, pp. 640-668. (in Latvian)
6. Company Claas KGaA mbH, Harsewinkel. Claas Areas 5543 Handbook (2007).
7. Башта Т.М. Объемные насосы и гидравличесткие двигатели гидросистем. (Volume Pumps and Hydraulic Motors of Hydraulic System.) Москва: Машиностроение, 1974. 606 c. УДК 62-82(075.8)
8. Яценко Н.Н., Прутчиков О.К. Плавность хода грузовых автомобилей. (The Release Motion of Trucks.) Москва: „Машиностроение”, 1968. 218c.

Janis Laceklis – Bertmanis, Aivars Kakitis, Eriks Kronbergs, Edgars Repsa and Mareks Smits

SLĖGIO SVYRAVIMAI HIDRAULINIO KELTUVO SISTEMOJE TRANSPORTO REŽIME

Anotacija

Straipsnyje pateikti slėgio svyravimai traktoriaus Claas Ares ATX 557 hidraulinėje sistemoje jam važiuojant su diskiniu kultivatoriumi per nelygumus.

Bandymai buvo atliekami važiuojant įvairiais greičiais ir esant įvairioms oro slėgio vertėms traktoriaus padangose su svyravimų slopintuvu ir be jo. Hidraulinėje sistemoje buvo įrengtas slėgio jutiklis, bandymų duomenys apdorojami panaudojant specialią programą. Agregatui važiuojant 8 km/h greičiu be svyravimų slopintuvo didžiausia slėgio vertė siekė 188 bar, o įjungus svyravimų slopintuvą didžiausia slėgio vertė neviršijo 170 bar. Agregato judėjimo per nelygumus modeliavimas buvo atliekamas panaudojant eksperimentinių tyrimų rezultatus. Modeliavimo metu maksimalus slėgis hidraulinėje sistemoje siekė tik 168 bar dėl sumažinto hidraulinio cilindro elastingumo koeficiento.

Traktoriaus hidraulinis keltuvas, slėgio svyravimai.

Янис Лацеклис-Бертманис, Айварс Какитис, Ерикс Кронбергс, Едгарс Репса и Мерекс Смитс

ИССЛЕДОВАНИЕ ПУЛЬСАЦИИ ДАВЛЕНИЯ В ГИДРОСИСТЕМЕ ТРАКТОРА В ТРАНСПОРТНОМ РЕЖИМЕ

Аннотация

В работе представлены результаты исследования колебаний давления в гидравлической системе трактора Claas Ares ATX 557 с дисковой бороной во время движения по искусственным неровностям. Эксперименты проводились на разных скоростях движения, с различным давлением воздуха в шинах и с применением системы гашения колебаний. Гидросистема трактора была оснащена датчиком давления, обработка данных проводилось с использованием специальной программы. При движении агрегата со скоростью 8 км/час без системы гашения колебаний максимальное давление в гидросистеме трактора достигало 188 бар. С применением системы гашения колебаний максимальное давление в гидросистеме трактора не превышало 170 бар. При моделировании движения трактора с дисковой бороной по неровностям была использована рабочая модель. Цилиндры Hitch-системы были заменены муфтами с пружиной и демпфером. Результаты моделирования были сопоставлены с результатами экспериментальных исследований. При моделировании снижение жесткости гидравлического цилиндра приводит к уменьшению величины давления до 168 бар при скорости движения 8 км / ч.

Гидросистема трактора, пульсации давления.