EVALUATION OF HYDRAULIC HITCH-SYSTEM IMPROVEMENT

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Abstract. In order to reduce the pressure oscillation in the hydraulic hitch-system of tractors and oscillation of all tractor aggregate the correction of hydraulic system parameters is used. The lower oscillation amplitudes can be achieved using the tractor aggregate implement as oscillation reducer. Equipment of hydraulic hitch-system with hydropneumatic accumulators lets adjust the stiffness and damping characteristics of the hydraulic system, limiting the pressure oscillation amplitude. Hydraulic pressure reduction, using hydropneumatic accumulators in the tractor hydraulic hitch-system lets to increase the driving speed of the tractor aggregate till 30 km·h^{-1} at the same hydraulic pressure oscillation level which is for the tractor aggregate at driving speed 10-15 km·h^{-1} without hydropneumatic accumulators. Transportation at 10 km long distance at the speed of 12.5 km·h^{-1} consumes time 0.8 h and 3.35 l fuel a day, but at the speed of 30 km·h^{-1} are 0.33 h consumed, but the fuel consumption increases by 0.6 liters. By increasing the movement speeds from 12.5 to 30 km·h^{-1} are 0.47 h saved a day that can be used in other agricultural work. By increasing the speeds of transport within the 30 km·h^{-1}, the working time is saved 9:33 h a month. The profit obtained from the saved time (9:33 h) per month is 66.38 EUR of salary economy. The profit per month from the time (9:33 h) used for plowing work is 57.17 EUR. The total profit per month from the saved time (9:33 h), excepting additional fuel costs 7.21 EUR is 116.34 EUR.

Key word: hydropneumatic suspension, tractor hitch-system hydraulic pressure oscillation.

Introduction

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

The pressure pulses in the hydraulic hitch-system mostly depend on the mounted soil cultivating aggregate weight and mass moment of inertia. Different implements attached to the tractor hitch-system cause different degrees of pressure pulsations. Changing the position of weight on the implement physical model different moment of inertia was obtained and the appropriate load on the hydraulic hitch-system hydraulic cylinder.

Modern tractor linkage system is fitted with the oscillation damper, what reduces the hydraulic hitch-system pressure oscillations. Equipment of a hydraulic hitch-system with hydropneumatic accumulators lets adjust the stiffness and damping characteristics of the hydraulic system, limiting the pressure oscillation amplitude. Compared to active oscillation damping system, it is possible to drive with higher speeds (till 30 km·h^{-1}) at the same hydraulic system pressure oscillation amplitude level, if the tractor is equipped with differently loaded hydraulic accumulators. For driving speeds 7.8 – 30 km·h^{-1}, experiments were carried out on a gravel road section, using the created hydraulic hitch-system loading tool with changeable weight position.

The tractor *Claas Ares 557 ATX* fuel consumption was determined with the aim to evaluate the increased driving speed economic gain for the tractor aggregate, using the recommended changes in the hydraulic hitch-system.

Materials and methods

Experiments on the second category road section were performed. In the experiments the same quality road section was used. The experimental road section was chosen circumstantial with the total length of 500 meters. Roughness width and length for the chosen road oscillate in wide margins. Roughness depth is from 0.2 to 0.1 m, but the length and width is in margins from 0.1 to 1.2 m.

The experiments are divided in two sections: at the first section the tractor *Claas Ares 557 ATX* hydraulic hitch-system working fluid maximal pressure oscillation amplitude values at the hydraulic cylinder and high pressure pump were determined. In the experiments four constant driving speeds 7.8, 13.7, 20 and 30 km·h^{-1} are used. All of constant driving speeds test times depend on the tractor aggregate driving speed. In the second section the *Claas Ares 557 ATX* fuel consumption was determined. For fuel consumption determination seven constant driving speed tests were used. The

whole constant driving speed test time is 60 seconds. In order to provide constant driving speed the tractor engine rotation frequency with the operating handle is set on a fixed position and switched gear. For fuel consumption the *AVL KMA Mobile* [1] device was used.

The driving speeds and driving distance at the tests depend on the engine rotation frequency and certain gear. According to literature [2], each experiment was repeated three times at certain gears and engine revolutions.

The advantage from the driving speed increase is saved time for the tillage tool transportation around the farm, which can be used for the main work, however, the disadvantage is that there is increased fuel consumption by increased driving speed. Economic evaluation was done for average transportation distance ~10 km, analyzing increase of speed during displacements from a field to field.

Results and discussion

Pressure in the hydraulic cylinder of the hitch-system is around 95 bar in static position, but 8 bar at the high pressure pump (pump is in unloaded position). If the hydraulic hitch-system is not being operated, pressure at the high pressure pump is being controlled by the safety valve or overflow valve. Some returning oil quantity from the pump is forwarded to the reservoir, but remainder part is forwarded for oiling of transmission components.

Fig. 1. shows the changes of the working fluid pressure oscillation values in the tractor hydraulic hitch-system hydraulic cylinder in transport position at tire pressure 1.2 bar. If the tractor active oscillation damper system is not used – the hydraulic hitch-system working fluid maximal pressure oscillation amplitude values at the hydraulic cylinder are 145 bar, at driving speed 30 km·h^{-1}, but if the active oscillation damper system is begin used at the same driving speed they reduce till 130 bar.

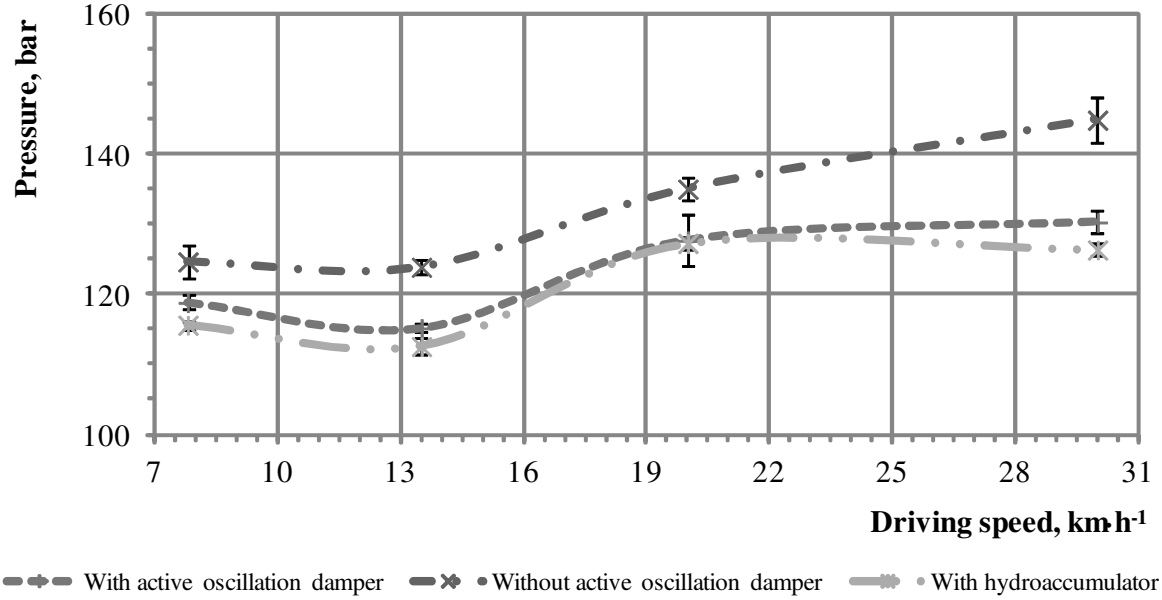

Fig. 1. **Characterictic curves of pressure changes in hydraulic cylinder by tire pressure 1.2 bar**

If three hydraulic accumulators (3 x 100 bar) are used, the maximal working fluid pressure oscillation value (see Fig. 1.) in the hydraulic cylinder of the hydraulic system is 127 bar, by driving speed 20 km·h^{-1}. In all experiments on a gravel road for the tractor aggregate with the driving speed up to 30 km·h^{-1} it was observed that the maximal working fluid pressure oscillation amplitude values in the hydraulic cylinder are for the version without the oscillation damping system, but the minimal values are by using hydraulic accumulators attached to the hydraulic hitch-system.

Switching on built-in active oscillation damping for the *Class Ares 557 ATX* tractor aggregate in the transport regime (20 – 30 km·h^{-1}) allows to reduce the working fluid maximal pressure oscillation amplitude values at the hydraulic cylinder (130±2 bar), but creates the working fluid pressure oscillation amplitude (Fig. 2.) up to 176±2 bar at the pump, but if the active pressure oscillation damping system is not used – the high pressure pump is in unloaded position (working fluid pressure oscillation amplitude at the high pressure pump is 15 bar).

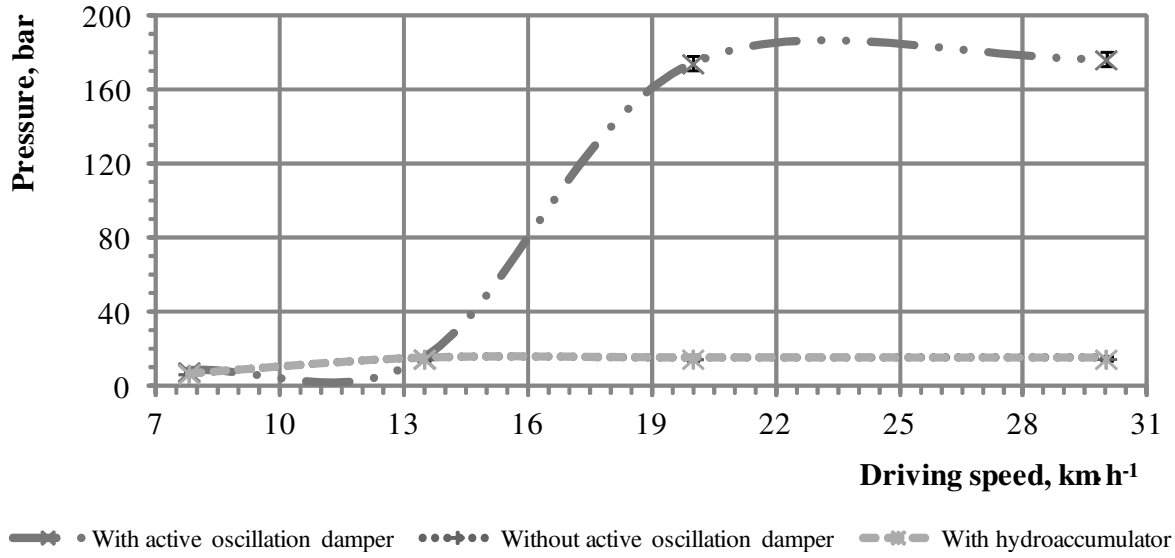

Fig. 2. **Maximal average pressure in hydraulic hitch-system of high-pressure pump circuit by tire pressure 1.2 bar**

Adding hydraulic accumulators to the hydraulic hitch-system allows reducing the maximal working fluid pressure oscillation amplitudes for 13 % by bigger driving speeds (20-30 km·h^{-1}) as compared with the tractor aggregate, which hydraulic hitch-system is not equipped with the pressure damper. Unlike from the active damping system caused increased pressure amplitudes in the pump contour (176±2 bar), usage of hydraulic accumulators allows to change the pump contour position to unloaded regime with pressure 15 bar. That is why adding of hydraulic accumulators is recommended for the tractor aggregate hydraulic hitch-system during the transportation regime with increased driving speed up to 30 km·h^{-1}.

The fuel consumption for the loaded tractor aggregate was experimentally determined for 10 km long (see Fig. 3.) gravel road with driving speed 5-37 km·h^{-1}.

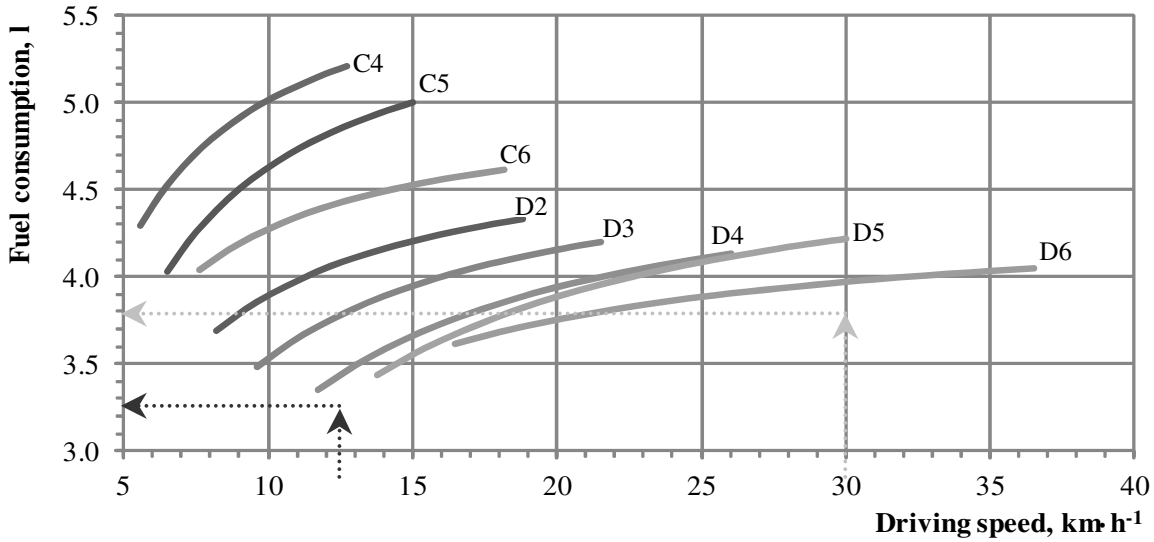

Fig. 3. **Driving speed and selected gear impact on fuel consumption for driving distance 10 km**

To finish 10 km distance by driving at 12.5 km·h^{-1} speed, it takes 0.8 h and 3.35 liters of fuel in *D4* gear, but at 30 km·h^{-1}, it takes 0.33 h, but fuel consumption increases by 0.6 liters. The trip time depends on the tractor class and configuration of its attached tool. Labor productivity for plowing is 0.72 ha h^{-1} and expenses on one hectare are 57.17 EUR. During the saved time extra 6.72 ha can be plowed. Expenses for these extra hectares would sum up to 384.18 EUR. Average markup is 15 % of plowed hectare expenses.

The saved time (9.33 h) for one month allows saving 66.38 EUR from salary, if one hour rate for a worker is 7 EUR. The profit from usage time during plowing per one month is 57.27 EUR. The total profit from saved time and increased driving speed in the transport regime, excluding extra fuel consumption cost of 7.21 EUR, is 116.34 EUR per one month.

Reconstruction cost assessment for the hydraulic hitch-system of the tractor aggregate. Exploitation costs include equipping the hydraulic hitch-system with hydraulic accumulators and maintenance costs. The expense division into fixed and variable costs is depending on the time period, for which expenses are being calculated [3; 4].

Total reconstruction cost for the tractor hydraulic system is calculated by equation:

$$\sum I_{Piel..} = I_m + I_r + I_{uzt.}, \quad (1)$$

where I_m – material cost, EUR;
I_r – mounting and producing costs, EUR;
$I_{uzt.}$ – exploitation cost, EUR.

Material and service costs on 18.01.2014. with VAT are summarized in Tables 1 and 2.

Table 1

Necessary material costs for adding hydraulic accumulators

No.	Materials	Unit of measurement	Quantity	Price, EUR	Amount, EUR
1.	Hose	M	1	11.66	11.66
2.	T-piece	Piece	1	8.37	8.37
3.	The piece	Piece	6	1.51	9.06
4.	Hydroaccumulator	Piece	4	110.03	440.12
5.	Hydroaccumulator charging	Piece	4	20.57	82.28
6.	Rolled steel square tubing 43x43	M	0.2	8.23	1.65
7.	Screw-bolt M8x1.25	Piece	8	0.03	0.24
				Total:	**553.38**

Table 2

Operating costs of hydraulic accumulator assembly

No.	Kind of work	Time, h	Price, EUR h^{-1}	Amount, EUR
1.	Production of unit for connecting of hydroaccumulators	8	5	40
2.	Production and mounting of unit for hydroaccumulator support	8	5	40
3.	Attaching the T-piece and hydroaccumulator to tractor hydraulic system	4	5	20
			Total:	**100**

The investment payback time is determined as prognosticated time that is needed to pay off the full investment. It is a period of time until the moment, when the capital investment costs are fully paid off by profit that is gained with these investments. The payback time is determined by formula:

$$G_{periods} = G_{PMSPA} + \frac{I_{NVAMS}}{I_{NLIAML}}, \quad (2)$$

where G_{PMSPA} – full month count before payoff;
I_{NVAMS} – uncompensated value at the start of payoff month, EUR;
I_{NLIAML} – money income in the whole payoff month, EUR.

The investment payback trough period (months), including maintenance costs, is shown in Table 3.

Investment for tractor hydraulic system pressure oscillation reduction, by installing hydraulic accumulators, will pay off in 5 working months and 2.7 working days.

Table 3

Expenses payback time trough months

Period, month	Prognosticate cash flow, EUR	Exploitation expenses of hydroaccumulator, EUR	Cumulative cash flow, EUR
0	-653.38	0.00	-653.38
1	123.99	-40.00	-569.39
2	123.99	0.00	-445.40
3	123.99	-40.00	-361.41
4	123.99	0.00	-237.42
5	123.99	0.00	-113.43
6	123.99	0.00	+10.56

Conclusions

1. To finish 10 km distance by driving the tractor *Claas Ares 557 ATX* at 12.5 km·h^{-1} speed, it takes 0.8 h and 3.35 liters of fuel in *D4* gear, but at 30 km·h^{-1}, it takes 0.33 h and the fuel consumption increases by 0.6 liters.
2. Increasing the driving speed from 12.5 to 30 km·h^{-1} it is possible to save 0.47 h per one day that can be used for agricultural main work realization.
3. The total profit for the tractor aggregate (*Claas Ares 557 ATX*) in transportation regime, from increasing the driving speed from 12.5 to 30 km·h^{-1} and saving time, is 116.34 EUR per month.
4. The investment for working fluid pressure oscillation amplitude reduction in the tractor hydraulic system, using hydraulic accumulators, will payoff after ~ 6 working months.

Acknowledgement

The paper is written by financial support of the 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).

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