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Modelling of the hydraulic scheme for loading the sowing sections of sowing machines for energy recovery

Abstract. One of the most promising areas for improving the energy efficiency of machines is the use of energy recovery from its source. The study aims to develop a basic hydraulic scheme of the clamping mechanism of the sowing section, which would allow to recovery of the energy of the oscillatory movement of the sowing section relative to the sowing frame. The paper considers the scheme of using hydraulic loading of sowing sections using a single-acting hydraulic cylinder. To collect the energy of the sowing section of the seeder, it is proposed to install a hydraulic motor in the existing hydraulic loading circuit to convert the hydraulic energy of the system into the mechanical energy of rotation of its output shaft and a system of check valves to redirect the working fluid in the system and ensure that the hydraulic motor shaft rotates in one specified direction. The input parameters of this system are unevenness of the soil, design features of the sowing section of the seeder, and forward speed of the seeder. The influence of the main parameters of the hydraulic cylinder,

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hydraulic accumulator and hydraulic motor of the system on the rotational speed and torque on the hydraulic motor shaft is investigated. The research shows that under certain external conditions, when modelling the system in the MATLAB Simulink software, the forced reciprocating motion of the hydraulic cylinder piston is converted into the rotational motion of the hydraulic motor output shaft, which, under certain system parameters under study, can rotate at a speed of 6-86 rpm, developing a theoretical torque of up to 22 N·m. The size of the hydraulic cylinder piston has the greatest influence on the output characteristics of the system. The hydraulic accumulator provides smoothing of pulsations, the magnitude of which, like the total pressure in the system, depends on the pressure of its pre-charging. The results of this study can be applied in agriculture to optimise energy use during the sowing process by developing efficient energy recovery systems for sowing machines, which will reduce fuel consumption and negative environmental impact

Keywords: seeder section, hydraulic cylinder, hydraulic accumulator, hydraulic motor, MATLAB Simulink

INTRODUCTION

Energy vehicles with internal combustion engines that use fossil fuel energy are the main performers of all mechanised operations in the field when growing crops. Therefore, the main task of agricultural machinery developers is to improve the energy efficiency of these machines by reducing energy consumption during the performance of specified technological operations. There are many ways to improve the energy efficiency of agricultural machinery: improving the design of the working bodies of these machines, changing the operating modes of the working units, or changing the energy source from an internal combustion engine to electric drives powered by electrical energy from batteries, electrical networks, etc. A. Bonavolontà *et al.* (2019) believe that the use of energy recovery in machine operation is a very promising way to improve energy efficiency. Many researchers are working towards harnessing this energy recovery potential in various mechanisms and machines. One of the main conditions for such research is the presence of "free" kinetic or potential energy in machines and the ability to "capture" such energy. Agricultural machines also have the potential to generate renewable energy, which is mostly converted into heat and dissipated. For instance, in the case of precision seed drills with working bodies placed on separate movable sections, when the field surface is copied by individual sections, these sections move spontaneously up and down relative to the main frame of the seed drill, the energy of this movement is often lost in the clamping mechanisms of the sections and is spent on heating the springs of these loading systems.

The clamping mechanisms of the sectional working bodies of the seeders are designed to create additional pressure on the working bodies when performing operations related to penetration into the soil or cutting plant residues noted by A. Sharda *et al.* (2017) note. Springs are used to generate the downward force on the sowing section. Pneumatic or hydraulic cylinders are also used instead of springs to increase the range of clamping forces. The hydraulic pressurisation systems of the sowing sections of precision seed drills can be equipped with single or double-acting hydraulic cylinders as the main actuators. Double-acting hydraulic cylinders forcibly lower and raise the suction pressure or automatically change it depending on the soil conditions. S.S. Virk *et al.* (2021) note that the introduction of such regulations facilitates the introduction of precision farming systems, as they allow for automatic response to external changes in the system.

Similar to the processes of lifting and lowering the sowing sections of the seeders while tracing the soil surface is the movement of the vehicle suspensions, which has already been sufficiently studied in terms of energy recovery. As such, M.N.Awad *et al.* (2018) addressed hydropneumatic regenerative car suspension systems. This regenerative system contains a double-acting hydraulic cylinder, a hydraulic rectifier with a check valve system, two hydraulic accumulators in the high and low-pressure lines, an unregulated hydraulic motor designed to rotate the shaft of an electric generator, the energy from which is stored in the accumulator battery. The performance of the developed hydropneumatic scheme was compared with conventional mechanical suspension, and hydropneumatic suspension using a double-acting hydraulic cylinder and a single-acting one. The proposed suspension system allows for collecting up to 20% more energy than its counterparts, and it is concluded that the larger size of the hydraulic accumulator can significantly improve the stability of the hydraulic motor and, accordingly, the entire regenerative system (accumulators with a volume of 0.16, 0.35, 0.5 and 0.75 litres were studied).

The research into energy recovery systems is also being extended to material-handling machines such as excavators and telescopic handlers. The potential energy of the load and the actuator itself is converted into a source for energy recovery and storage when they are lowered. J. Li *et al.* (2020) found that a hydraulic cylinder designed to lift and lower loads becomes the main actuator in energy recovery. The working system can also include a hydraulic accumulator when energy is stored in the form of compressed gas, or a hydraulic motor. With the help of a hydraulic motor, through its output shaft, which can be connected to the input shaft of a generator, energy can be stored in the form of an electric current in batteries or, when the hydraulic motor shaft is connected to a flywheel, energy can be stored in the form of kinetic energy of a spinning mechanical drive.

Another example of energy production using hydraulic systems is given by Z. Fang *et al.* (2021), employing the principle of the up-and-down motion of a body floating on the water surface to convert the kinetic energy of a sea wave first into mechanical and then into electrical energy; the main actuators here are also double-acting hydraulic cylinders that create a directed flow of working fluid inside the hydraulic system, which also contains a check valve system, high and low-pressure hydraulic accumulators, and a hydraulic motor whose output shaft is connected to the shaft of the electrical energy generating plant.

Thus, there are many developments and studies of clamping systems for seeder sections, but they have not been investigated in terms of the possibility of recovering the energy of the lifting and lowering movement of the sections. Furthermore, the issue of obtaining regenerative energy from the reciprocating motion of hydraulic cylinders, which are actuators in-vehicle shock absorbers, lifting machines, etc. is sufficiently covered in the literature, but the obtained patterns need to be adapted and investigated for the operating conditions of a precision seeder.

This study aims to create a basic hydraulic scheme for the pressing mechanism of the sowing section of the seeder, which provides the possibility of using the energy arising from the vibrations of the sowing section compared to the seeder frame.

Figure 1. Hydraulic loading of the sowing section using a single-acting hydraulic cylinder RFX Hydraulic Planter Down Pressure System
Source: Precision Farming Dealer (2015)

MATERIALS AND METHODS

One of the simplest schemes of using hydraulic loading of sowing sections with the use of a single-acting hydraulic cylinder is considered. For example, such a scheme is proposed in the RFX Hydraulic Planter Down Pressure System by Dawn Equipment Company (USA), which aims to maintain a given pressure on the working bodies of the sowing section of the seeder (Fig. 1).

When using this scheme, the pressure on the sowing section is set according to the pressure gauge using a valve mechanism. The hydraulic accumulator acts as a shock-absorbing element, taking over the overloads that occur in the system due to the spontaneous movement of the sections up and down due to uneven field surfaces.

To collect the energy of the oscillatory movement of the sowing section of the seeder, it is proposed to install a hydraulic motor to convert the hydraulic energy of the section's movement into hydraulic energy in the existing hydraulic loading circuit, which contains a hydraulic cylinder as the main actuator for converting the mechanical energy of the section's movement into hydraulic energy, and a system of check valves to redirect the working fluid in the system and ensure the rotation of the hydraulic motor shaft in one given direction (Fig. 2).

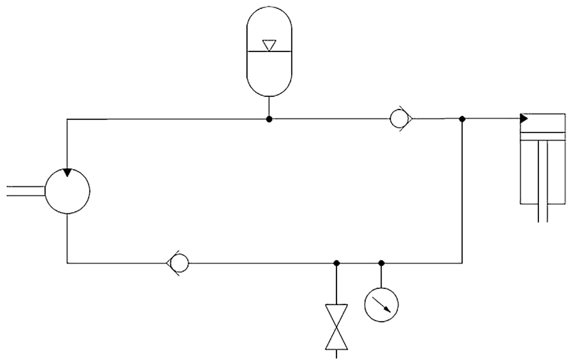

Figure 2. Schematic representation of the proposed system for energy recovery of the oscillatory movement of the sowing section of the seeder
Source: compiled by the authors

The study of the proposed energy recovery system was carried out with the help of MATLAB Simulink software using the internal libraries of hydraulic and measuring equipment (Fig. 3).

The main actuating elements of this system were a hydraulic cylinder, the parameters of which determine the pressure and flow rate of the working fluid in the closed system of loading the sowing sections, a hydraulic accumulator that determines the rigidity of the system, and a hydraulic motor, through the output shaft of which energy was extracted from the system, the size of which can be estimated through its rotational speed and the torque generated, which represents the energy capacity of this system. A hydraulic accumulator is installed after the hydraulic cylinder and before the hydraulic motor to smooth out the pulsations of the working fluid entering the hydraulic motor (Awad *et al.*, 2018).

The input parameters of this system were: soil irregularities, which in MATLAB are expressed as harmonic oscillations of the seeder section with a certain amplitude (responsible for the amount of change in the vertical component of the section position and the movement of the hydraulic cylinder piston (Fig. 4)); design features of the sowing section of the seeder (a parallelogram suspension system for connecting the sowing section of the seeder to its frame was studied); the translational speed of the seeder as the main dynamic characteristic (an increase in the speed of movement leads to an increase in the supply of working fluid by the hydraulic cylinder rod) (Voitik *et al.*, 2021).

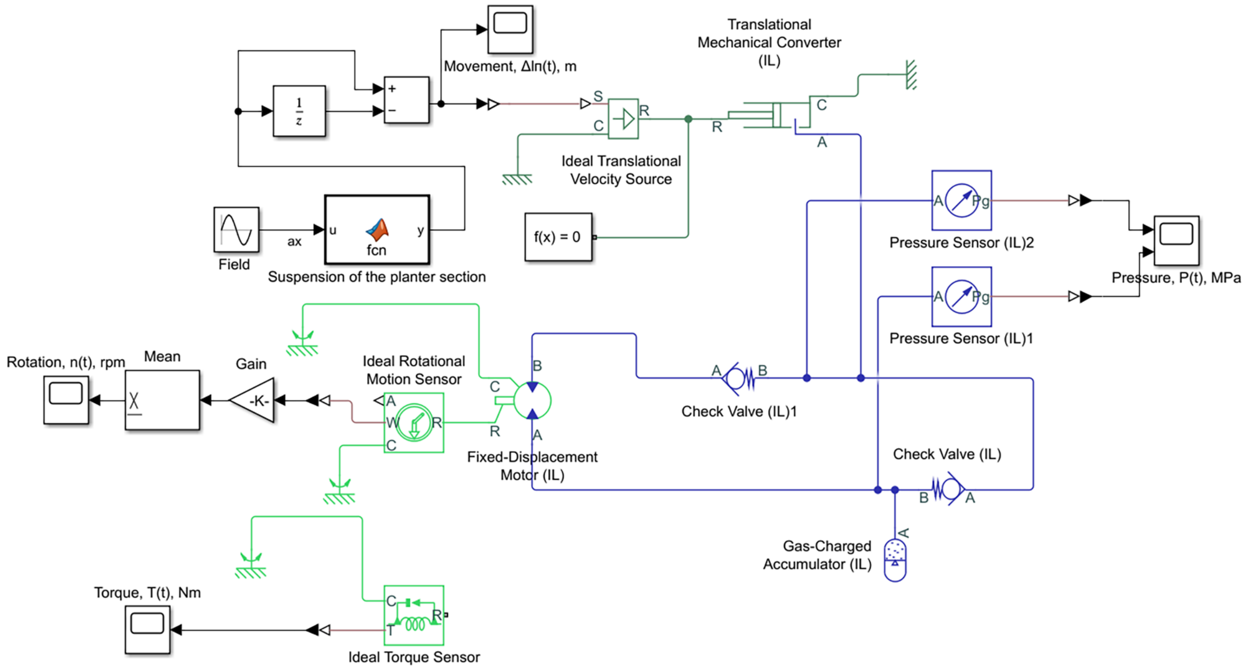

Figure 3. The model of energy generation from the movement of the sowing section of the seeder is compiled in the MATLAB Simulink program field

Source: compiled by the authors

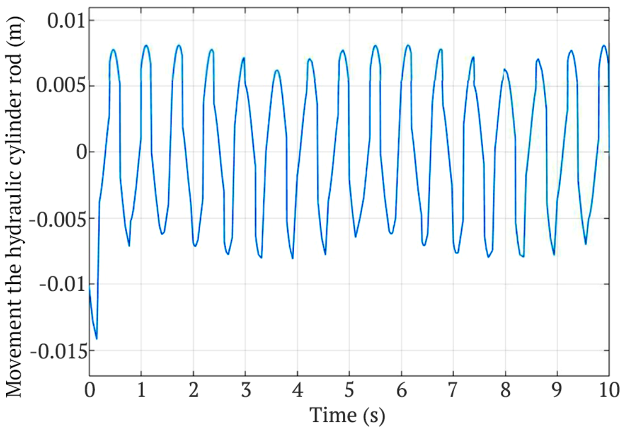

Figure 4. Movement of the hydraulic cylinder rod when the sowing machine is in motion

Source: compiled by the authors

The equation (Voitik *et al.*, 2021) was used to determine the amount of stroke of the hydraulic cylinder rod during the translational movement of the seeder within the parallelogram suspension of the sowing section:

$$\Delta l_n(\vartheta) = \sqrt{a^2 + b^2 + 2ab \cdot cos(0{,}5\pi - arcsin(\vartheta))}, \quad (1)$$

where Δl_n – stroke length of the hydraulic cylinder rod of the parallelogram section suspension, m; ϑ – variable that determines the position of the working bodies relative to the central frame beam; a – length of the short link of the suspension parallelogram, m; b – length of the long link of the suspension parallelogram, m.

Next, the MATLAB Simulink internal block The Ideal Translational Velocity Source measured the velocity of the rod according to the formula:

$$\upsilon = \upsilon_R - \upsilon_C, \quad (2)$$

where υ_R and υ_C – absolute speeds at ports *R* and *C* respectively (Fig. 3).

This unit is an ideal velocity source that generates velocity in proportion to the input physical signal. A source is ideal in the sense that it is considered powerful enough to maintain a given speed regardless of the force acting on the system.

To represent the hydraulic cylinder, the Translational Mechanical Converter (IL) block was selected, which reflects the relationship between an isothermal fluid and a mechanical system, i.e. converts mechanical force into isothermal fluid pressure and vice versa. The hydraulic cylinder in this recovery system worked as a pump, acting as a converter of mechanical energy of the sowing section movement into hydraulic energy of the working fluid flow.

$$Q(t) = S \cdot h(t), \quad (3)$$

where $Q(t)$ – hydraulic cylinder supply of the hydraulic fluid, m³/c; S – piston surface, m²; $h(t)$ – piston velocity, m/s. The main parameters of the hydraulic cylinder are the piston stroke, which depends on the unevenness of the field, and the piston diameter. Manufacturers of seed drills and sowing section pressing systems mainly use hydraulic cylinders with a piston diameter of 40-50 mm (Zhou *et al.*, 2023). Therefore, this size was used as a baseline for further research. To redirect the working fluid to the hydraulic motor inlet, the system is equipped with two Check Valves that allow the fluid to flow in only one direction. The locking elements of the valves started to open when there was a pressure difference of 0.5 bar in the working fluid, and the diameter of the passage hole of the selected valves was 11 mm.

When overcoming obstacles, the piston of the hydraulic cylinder must reciprocate relative to its body, while the compression movement will occur when the initial pressure set in the system is overcome, which provides the necessary downforce of the sowing section. Since the hydraulic system's working fluid is incompressible, the hydraulic accumulator plays the role of a shock absorber and volume compensator in this system. The main parameters for the study of the accumulator were its volume, which determines the amount of working fluid that it can accept to compensate for the movement of the hydraulic cylinder piston, and the precharge pressure in its gas part, which is recommended to be set at 60-90% (Dindorf *et al.*, 2023) of the set pressure in the hydraulic clamping system, but at the same time, the damping properties of the system depend on the precharge pressure of the accumulator: the greater the pre-charging pressure of the hydraulic accumulator, the stiffer the system.

The Gas-Charged Accumulator (IL) block simulates a gas-charged hydraulic accumulator in an isothermal fluid system. The battery contains a pre-charged gas chamber and a liquid chamber. The chambers are separated by a membrane. According to the description from the MATLAB Simulink library, the total volume of the hydraulic accumulator V_T is divided by the membrane into a liquid chamber with a potential volume V_L and a gas chamber with a potential volume V_G. The volume of liquid in the V_C liquid chamber is always less than the total volume of the battery, so the gas volume is never zero:

$$V_L = V_T - V_G, \tag{4}$$

$$V_C = V_T - V_{dead}, \tag{5}$$

where V_T – overall hydraulic accumulator volume, V_L – volume of liquid in the hydraulic accumulator, V_G – gas volume in the hydraulic accumulator, V_C – capacity of the liquid chamber of the hydraulic accumulator (V_T - V_G), V_{dead} – the part of the gas chamber that remains filled with gas when the liquid chamber is full.

The contact pressure of the hard stop was modelled based on the specified stiffness and damping properties. The ratio of gas pressure and gas volume between the current state and the pre-charge state was polytropic, and the pressure was balanced on the membrane of the hydro accumulator:

$$P_G V_G^{ksh} = P_{pr} V_T^{ksh}, \tag{6}$$

where P_G – gas pressure in the gas part of the accumulator, P_{pr} – precharge pressure of the gas part of the accumulator (when there is no liquid in the liquid part of the accumulator), k_{sh} – coefficient of specific heat capacity (assumed to be 1.4). Since the system considers only one sowing section with one hydraulic cylinder, a 1-litre hydraulic accumulator was used as the basis.

The actuating mechanism of the proposed system was an unregulated hydraulic motor, through the output shaft of which the hydraulic energy created by the hydraulic cylinder would be converted back into mechanical energy for further transformation. This element is represented by the Fixed-Displacement Motor (IL) block, which models an engine with a constant displacement. The main characteristic of a hydraulic motor is its displacement - the speed of rotation of its shaft and torque will depend on the displacement of the hydraulic motor (Zou *et al.*, 2017):

$$n = \frac{Q}{q}\eta_v, \tag{7}$$

$$T = \frac{\Delta P q}{2\pi}\eta_m, \tag{8}$$

where n i T – rotational speed and torque of the hydraulic motor output shaft, respectively; q – engine displacement; Q – the flow of working fluid passing through the hydraulic motor; ΔP – pressure drop between the inlet and outlet of the hydraulic motor; η_V and η_m – respectively, volumetric efficiency and mechanical efficiency of the hydraulic motor. According to J. Mi *et al.* (2017), a hydraulic motor with a displacement of 20 cm^3/rev was used as a basis. To measure the pressure upstream and downstream of the hydraulic accumulator, Pressure Sensor units with the settings to show gauge pressure were used. This block displays the physical pressure difference between the P and P_g sensor ports (Fig. 3). The main initial data for the study of the hydraulic model of energy recovery from the movement of the sowing section of the precision seeder in MATLAB Simulink are given in Table 1.

Table 1. Initial data for research

No.	Parameter	Value
1	Length of the short link of the parallelogram, m	0.2
2	Length of the long link of the parallelogram, m	0.4
3	Driving speed of the sowing machine, m/s	3
4	Bump wavelength, m	0.3
5	Height of field irregularities, m	0.02
7	Hydraulic cylinder piston diameter, m	0.04; 0.06; 0.08
8	Hydraulic accumulator capacity, l	1
9	Initial charging pressure of the hydraulic accumulator, bar	20; 30; 40

Continued Table 1.

No.	Parameter	Value
10	Displacement of the hydraulic motor, cm^3/rev	10; 20; 30
11	Nominal hydraulic motor pressure drop, MPa	10
12	Volumetric efficiency of the hydraulic motor	0.92
13	Mechanical efficiency of the hydraulic motor	0.88
14	Diameter of the valve bore, mm	11

Source: compiled by the authors

To obtain the output parameters on the hydraulic motor shaft, the Ideal Rotational Motion Sensor and Ideal Torque Sensor blocks are used to measure the shaft rotation speed and torque, respectively. Both units operate in "ideal" conditions, without considering inertia, friction, energy losses, etc. The Ideal Rotational Motion Sensor unit measures the rotational speed in rad/s, so the Gain auxiliary unit is used to convert these revolutions to rpm, and the Mean unit is used to display the average values of the hydraulic motor shaft rotation on the oscilloscope display. During the research, these blocks were connected to the output shaft of the hydraulic motor in turn, separately from each other.

RESULTS AND DISCUSSION

The main purpose of the proposed scheme for loading the sowing sections of precision seeders was to obtain energy from the spontaneous movement of these sections relative to the seeder frame on the output shaft of the hydraulic motor, which can be estimated by its rotational speed and the torque generated by it. Therefore, the influence of the main parameters of the system on the efficiency of the hydraulic motor, namely the parameters of the hydraulic cylinder, hydraulic accumulator and, directly, the hydraulic motor itself, was investigated.

When varying the size of the hydraulic cylinder piston, it should be borne in mind that the volume of working fluid it pushes out depends on the size of the piston stroke and its diameter, while at the same pressure, the size of the hydraulic cylinder piston diameter affects the pressing force of the sowing section, according to Pascal's law. That is, the larger the piston diameter, the lower the pressure in the system should be, and also, such a hydraulic cylinder as a pump can create a greater flow of working fluid for the same period, which was confirmed by the corresponding simulation graphs in MATLAB Simulink, which show the dependence of the rotation speed of the hydraulic motor output shaft on the size of the hydraulic cylinder piston diameter (Fig. 5a).

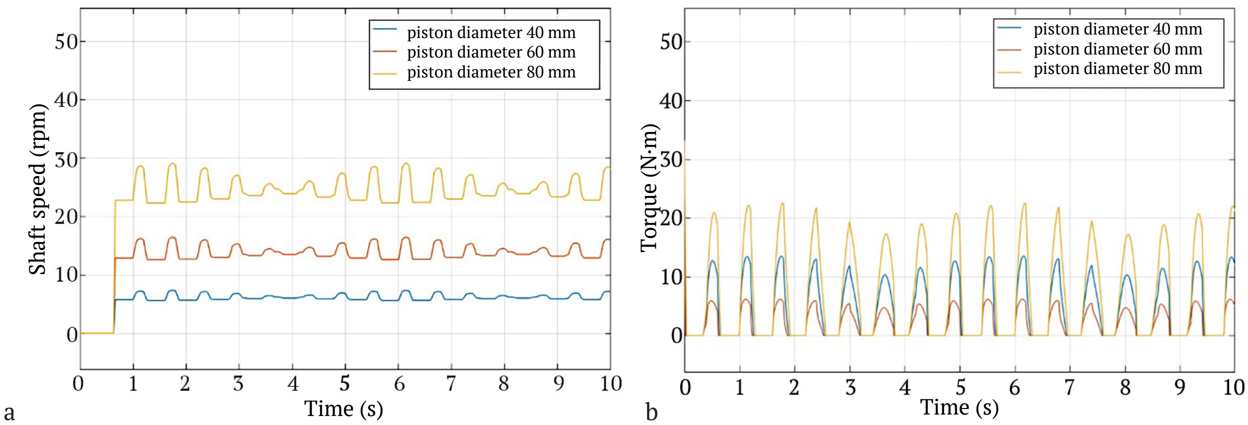

Figure 5. Rotational speed (a) and torque (b) on the shaft of the hydraulic motor of the clamping system
Note: with variable hydraulic cylinder piston dimensions a constant hydraulic motor displacement of 30 cm^3/rev and a precharge pressure of 30 bar
Source: compiled by the authors

As can be seen from the graph (Fig. 5a), the rotational speed of the hydraulic motor shaft was on average 8, 14 and 25 rpm with the corresponding hydraulic cylinder piston diameters of 40, 60 and 80 mm. The amount of torque on the hydraulic motor shaft (Fig. 5b) also increased with increasing hydraulic cylinder piston diameter: the peak values increased from 6 N·m at a hydraulic cylinder piston diameter of 40 mm to 12 N·m at a hydraulic cylinder piston diameter of 80 mm. During the research, the nominal pressure losses at the inlet and outlet of the hydraulic motor were assumed to be 10 MPa. Similar trends can be seen in the work of P. Zheng *et al.* (2019). When determining the optimal parameters of a hydroelectric regenerative vibration damping system in car suspension systems, the effect of the piston diameter of a hydraulic cylinder that perceived the main shock loads from road irregularities was investigated. In the experiments, when the piston diameter increased from 25 to 50 mm, the rotational speed of the hydraulic motor shaft increased from 300 to 1100 rpm, and the power increased from 10 to 220 watts. Thus, it is possible to conclude that the dimensions of the hydraulic cylinder piston are one of the decisive factors influencing the efficiency of the regenerative component of the proposed energy recovery system since the rotational speed of the hydraulic motor output shaft and its torque will determine the amount of energy that this system can generate.

To analyse the effect of the hydraulic accumulator parameters on the system operation, the study investigated how changing its precharge pressure affects the kinematic and dynamic parameters of the system, namely, smoothing the fluid pressure fluctuations after the hydraulic cylinder is supplied (Fig. 6) and directly on the rotational speed and torque on the hydraulic motor shaft (Fig. 7).

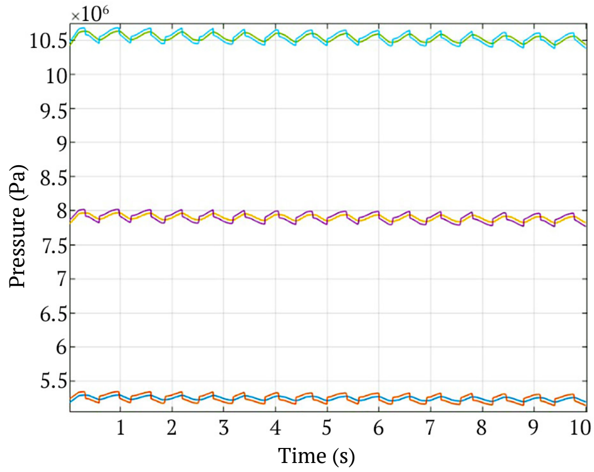

Figure 6. System pressure upstream and downstream of the accumulator at 20, 30 and 40 bar accumulator precharge pressure
Note: with a constant hydraulic motor displacement of 20 cm^3/rev and a hydraulic cylinder piston diameter of 60 mm
Source: compiled by the authors

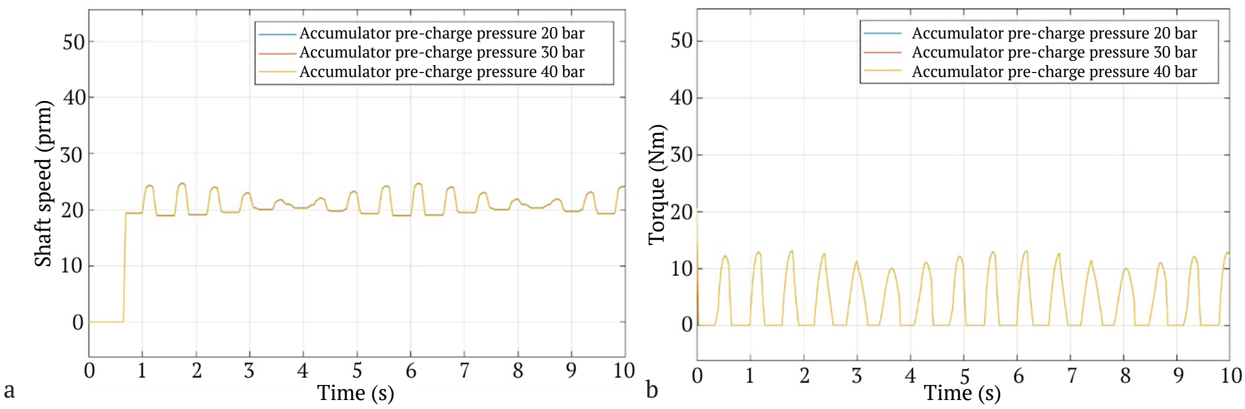

Figure 7. Rotational speed (a) and torque (b) on the shaft of the hydraulic motor of the clamping system
Note: at variable pre-charging pressure of the hydraulic accumulator and constant working volume of the hydraulic motor of 20 cm^3/rev and piston diameter of the hydraulic cylinder of 60 mm
Source: compiled by the authors

As can be seen from the graph (Fig. 6) the hydraulic accumulator acts as a pulsation smoothing device, reducing the peak fluctuations that occur when the hydraulic cylinder rod moves. This ensures more stable operation of the hydraulic motor and more even rotation of its output shaft. The lower the pre-charging pressure of the accumulator, the lower the pulsation amplitude after the accumulator. But it is also worth noting that the pre-charging pressure of the hydraulic accumulator directly affects the overall pressure of the loading system: when the pre-charging pressure of the hydraulic accumulator was doubled from 20 to 40 bar, the pressure in the clamping system also increased from 5.3 to 10.6 MPa. This factor must be addressed when designing the regeneration system, as it directly affects the downward force on the working members of the seed drill section.

After analysing the graphs (Fig. 7), it is possible to conclude that the value of the pre-charging pressure of the hydraulic accumulator, in our case, does not affect such parameters of the hydraulic motor as the speed of rotation of its output shaft and the torque on it. Similar conclusions about the role of a hydro accumulator in a regenerative system were made by P. Zheng *et al.* (2019), who traced the effect of changing the volume of the hydraulic accumulator on the kinematic and energy parameters of the hydraulic motor output shaft in such a system. They noted that changing the parameters of the hydraulic accumulator has the least impact on the average speed of rotation of the hydraulic motor shaft and its torque, although in their studies, increasing the volume of the hydraulic accumulator from 0.63 to 1 litre led to a decrease in the speed of rotation of the hydraulic motor shaft within 30 rpm and a decrease in power within 50 W, under the conditions of their experiments. The output shaft speed of the hydraulic motor is directly proportional to the flow rate of the working fluid and inversely proportional to the working volume of the hydraulic motor. The amount of torque depends on the pressure drop between the inlet and outlet of the hydraulic motor and is directly proportional to the displacement of the hydraulic motor. These facts can be seen in the graphs (Fig. 8) when performing simulations in MATLAB Simulink with changes in hydraulic motor parameters.

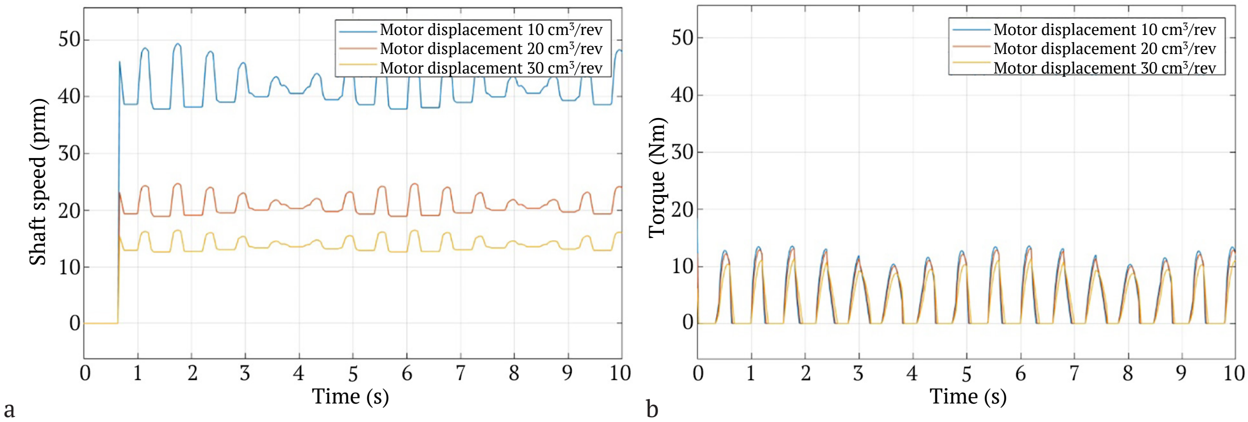

Figure 8. Rotational speed (a) and torque (b) on the shaft of the hydraulic motor of the clamping system
Note: when its working volume changes the precharge pressure of the hydraulic accumulator is constant at 30 bar and the piston diameter of the hydraulic cylinder is 60 mm
Source: compiled by the author based on research

Analysing the graph (Fig. 8a), it is possible to note that with a decrease in the working volume of the hydraulic motor from 30 to 10 cm^3/rev, the rotational speed of the hydraulic motor shaft increases at its peak values from 17 rpm to 42 rpm. A similar trend was observed by P. Zheng *et al.* (2019), in which a decrease in the working volume of the hydraulic motor from 8.94 to 5.77 cm^3/rev led to an increase in the speed of rotation of the hydraulic motor shaft from 600 to 1000 rpm. The effect on the torque (Fig. 8b) of the hydraulic motor displacement, in this case, is the opposite: with an increase in the hydraulic motor displacement, the torque increases from 11 to 13 Nm at its peak values. The difference is small, which can be explained by the fact that in MATLAB Simulink, in the hydraulic motor properties, the same nominal pressure drop was set for all three studies with different hydraulic motor displacements. The results obtained are in line with the studies conducted by J. Zou *et al.* (2017). When studying the regenerative vehicle suspension system, the researchers obtained clear results of the effect of the hydraulic motor displacement on the energy performance at its output shaft. By changing the working volume of the hydraulic motor from 8 to 12 cm^3/min in increments of 1 cm^3/rev, and taking into account the change in the speed of the hydraulic motor output shaft, they obtained a steady increase in power from 2200 to 5000 W on this shaft.

Recent studies have shown that the use of recuperation systems on various types of machines helps to improve their efficiency. For example, for machines with lifting mechanisms, the reduction in energy consumption due to the accumulation of electrical energy can range from 17% (Wang & Wang, 2013) to 54-58% (Minav *et al.*, 2012; Yu & Ahn, 2019). For systems with energy storage in the form of pressure up to 50-70% (Zhao *et al.*, 2017; Xia *et al.*, 2018). The use of flywheels reduces energy consumption for excavator operations by up to 44%-62% (Choi *et al.*, 2015; Li *et al.*, 2020).

The results of the research on modelling the energy generation from the oscillatory movement of the sowing section relative to the seeder frame, made in the MATLAB Simulink software, show that with predefined system parameters, it is viable and can implement the rotation of the hydraulic motor output shaft with a certain frequency and torque for further accumulation or use of the generated energy flow. Analysing the physical data obtained on Simulink oscilloscopes, it is possible to state that the actual values of rotational speed and torque have patterns similar to those obtained by other scientists in the study of car suspension systems. This can be explained by the similarity of the process, when an external disturbance causes the hydraulic cylinder to move, as well as the similarity of the equipment. However, in the studies, the values of the hydraulic motor shaft speed and power are higher than those obtained in this study. This difference can be explained by the fact that the vehicle's movement on the road has much higher speeds and, accordingly, higher dynamic characteristics compared to the movement of the seeder in the field, which contributes to a greater number of working strokes of the hydraulic cylinder rod, which is the basis of the shock absorber. In addition, all the reviewed works on energy recovery in car suspension systems use double-acting hydraulic cylinders, which makes linear movements of the hydraulic cylinder rod in both directions work. Thus, to optimize the performance of a hydroelectric regenerative vehicle suspension system, B. Gong *et al.* (2016) investigated the regenerative system of a hydraulic electromagnetic shock absorber for vehicles. The hydraulic part of this system includes a double-acting hydraulic cylinder, a hydraulic accumulator, and a system of check valves that direct the working fluid from both chambers of the cylinder to a nonreversible hydraulic motor, which directly rotates the shaft of the power generator.

CONCLUSIONS

A basic hydraulic diagram of the clamping mechanism of the sowing section was developed, which would allow to recovery of the energy of the oscillatory movement of the sowing section relative to the sowing frame, and its operation was modelled in the MATLAB Simulink program. The research shows that under certain external conditions, namely the magnitude of field irregularities, the speed of the seeder and the design parameters of the parallelogram mechanism of the sowing section, and the pre-accepted parameters of the main structural elements, namely the hydraulic cylinder, hydraulic accumulator and hydraulic motor, this system will be able to function. When the system was modelled in MATLAB Simulink, the forced reciprocating motion of the hydraulic cylinder piston was converted into the rotational motion of the hydraulic motor output shaft, which, with certain system parameters under study, can rotate at a speed of 6-86 rpm, developing a theoretical torque of up to 22 N·m. The size of the hydraulic cylinder piston has the greatest influence on the output characteristics of the system. The rotational speed of the hydraulic motor shaft was on average 8, 14 and 25 rpm at the corresponding hydraulic cylinder piston diameters of 40, 60 and 80 mm, and the torque value increased with increasing hydraulic cylinder piston diameter: from 6 N·m with a hydraulic cylinder piston diameter of 40 mm to 12 N·m with a hydraulic cylinder piston diameter of 80 mm. However, the design parameters of the hydraulic cylinder require additional justification, as it is also the main actuating element of the pressing system of the sowing section of the seeder. The hydraulic accumulator provides pulsation smoothing, the magnitude of which, like the total system pressure, depends on the precharge pressure of the hydraulic accumulator. However, the precharge pressure of the accumulator directly affects the total pressure in the system; when the precharge pressure of the accumulator was doubled from 20 to 40 bar, the pressure in the clamping system also increased from 5.3 to 10.6 MPa. The parameters of the hydraulic motor require additional research in terms of working with a certain number of sowing sections of the seeder because the research was carried out with only one sowing section. The study determined that reducing the hydraulic motor's displacement from 30 to 10 cm ^{3}/rev leads to an increase in the motor shaft speed from 17 rpm to 42 rpm, while the effect on its torque is inversely related to this parameter: as the displacement of the hydraulic motor increases, torque increases from 11 to 13 Nm. The system of further conversion, storage and use of recovered energy also requires separate research.

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CONFLICT OF INTEREST

None.

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Моделювання гідравлічної схеми довантаження висівних секцій посівних машин з метою рекуперації енергії

Анотація. Одним з перспективних напрямків підвищення енергоефективності машин є застосування рекуперації енергії створеної її джерелом. Метою даної роботи є розробка принципової гідравлічної схеми притискного механізму секції сівалки, яка б давала можливість рекуперувати енергію коливального руху висівної секції відносно рами сівалки. В роботі розглянуто схему використання гідравлічного довантаження висівних секцій з використанням гідроциліндра односторонньої дії. Для збирання енергії руху висівної секції сівалки пропонується в існуючу гідравлічну довантажувальну схему, встановити гідравлічний мотор для перетворення гідравлічної енергії системи в механічну енергію обертання його вихідного валу та систему зворотних клапанів для перенаправлення робочої рідини в системі і забезпечення обертання валу гідравлічного мотору в одному заданому напрямку. Вхідними параметрами даної системи є: нерівності ґрунту, конструктивні особливості висівної секції сівалки, поступальна швидкість руху сівалки. Досліджено вплив основних параметрів гідроциліндра, гідроакумулятора та гідромотора системи на швидкість обертання та крутний момент на валу гідравлічного мотору. Проведені дослідження показують, що за певних зовнішніх умов, при моделюванні системи в полі програми MATLAB Simulink примусовий зворотно-поступальний рух поршня гідроциліндра перетворився в обертальний рух вихідного валу гідромотора, який при певних досліджуваних параметрах системи може обертатися зі швидкістю в межах 6-86 об/хв, розвиваючи теоретичний крутний момент до 22 Н·м. Найбільший вплив на вихідні характеристики системи має розмір поршня гідроциліндра. Гідроакумулятор забезпечує згладжування пульсацій, величина яких, як і загальний тиск в системі, залежить від тиску його попереднього зарядження. Результати цього дослідження можуть бути застосовані в сільському господарстві для оптимізації використання енергії в процесі сівби через розробку ефективних систем рекуперації енергії висівних машин, що дозволить зменшити споживання палива та негативний вплив на навколишнє середовище

Ключові слова: секція сівалки; гідроциліндр; гідроакумулятор; гідромотор; MATLAB Simulink