Дослідження присвячено підвищенню ефективності технологічного процесу оранки ґрунту сільськогосподарських культур. На підставі проведених експериментальних досліджень технологічного процесу оранки визначено зусилля, що діють на механізм навіски трактора та польову дошку. Визначено, що універсальні корпуси плугів підвищують ефективність оранки за рахунок збільшення їх стійкості. Встановлено, що це приводить до зменшення енергоємності корпуса плуга при обробітку ґрунту, а також забезпечується рівномірне зношення тертьової поверхні за рахунок зміни їх поверхні. Визначено, що необхідно проводити вдосконалення вузлів і деталей ґрунтообробних машин з метою збільшення термінів напрацювання на відмову робочих органів і зменшення їх тягового опору. Встановлено, що не достатньо досліджено вплив поперечної сили тиску, що діє на польові дошки плуга. Не приділено уваги по визначенню величини тягового зусилля кожної тяги механізму навіски тракторного агрегату. Один із резервів підвищення технологічних показників і зниження енергоємності орного агрегату – це конструктивне вдосконалення стандартної польової дошки плуга. Під час експериментальних досліджень використано вимірювальну систему динаміки та енергетики мобільних машин, що відноситься до технічних засобів діагностування та експлуатаційного контролю. Тензорезистори встановлювали на польову дошку плуга, середньої, лівої та правої тяг механізму навіски трактора. Визначено, що середнє значення поперечної сили тиску, яка діє на польову дошку, що встановлена на стійці першого корпусу плуга, становить 1610–1668 Н. На стійці другого корпусу – 1525–1630 Н; на стійці третього корпусу – 1848–1870 Н. Пропонується застосувати замість стандартної польової дошки начіпного лемішного плуга ПЛН-3-35 плоско-округлий елемент у вигляді диску зі ступицею з горизонтальною віссю обертання. Диск перетворює сили тертя ковзання в сили тертя кочення. Використання диску приводить до зниження енергоємності плуга на 13–15 %. Завдяки цьому зменшується тягове зусилля корпусів плуга, підвищується їх стійкість, знижується витрата паливо-мастильних матеріалів

Ключові слова: плоско-округлий елемент, польова дошка, корпус плуга, борозневі колеса, леміш

UDC 631.312.44
DOI: 10.15587/1729-4061.2019.169903

STUDYING THE INFLUENCE OF STRUCTURAL-MODE PARAMETERS ON ENERGY EFFICIENCY OF THE PLOUGH PLN-3-35

O. Dzyuba
PhD, Assistant*
E-mail: nvodolagadtn@ukr.net

A. Dzyuba
PhD, Associate Professor*
E-mail: nvodolagadtn@ukr.net

A. Polyakov
PhD, Associate Professor
Department of Repair of Machines, Exploitation of Energy Resources and Labor Protection**
E-mail: anatoliy.polyakov67@gmail.com

V. Volokh
PhD, Senior Lecturer*
E-mail: volokh69vo@gmail.com
sviatchenko_la@ukr.net

R. Antoshchenkov
Doctor of Technical Sciences, Associate Professor, Head of Department
Department of Mechatronics and Machine Parts***
E-mail: roman.antoshchenkov@gmail.com

A. Mykhailov
PhD, Associate Professor
Department of Agricultural Machines***
E-mail: mixaylovshm@gmail.com

*Department of Mechanization of Production Processes in Agroindustrial Complex**
**Luhansk National Agrarian University
Slobozhanska str., 68, Starobelsk, Ukraine, 92703
***Kharkiv Petro Vasylenko National Technical University of Agriculture
Alchevskykh str., 44, Kharkiv, Ukraine, 61022

1. Introduction

One of the most important, time-consuming, and responsible operations during soil preparation in the autumn period is plowing. It is necessary to plow the remains of stems of agricultural crops, which are organic fertilizers, as well as to accumulate moisture in soil over a winter-spring period for obtaining a stable harvest of agricultural produce.

The basic working bodies that ensure the quality of tillage are a plough's casings. A plough's casings operate in an abrasive soil environment and rapidly wear out, thereby changing their shape and size. The mean time between failures for the working bodies of a plough is: ploughshare – 5–20 ha; heap fronts – 100 ha; landsides – 20–60 ha [1].

To improve the mean time between failures and to reduce the traction resistance of working bodies, it is necessary to improve the nodes and parts of tilling machinery.

2. Literature review and problem statement

Paper [1] emphasized that the reversible ploughs ensure smooth plowing without a separated furrow. Such manufacturers of agricultural machinery as «Lemken», «Rverneland» or «Vogel Noot» design the mounted and attached ploughs with a wide range of plough casings. Ploughs differ in a capture width, the shape and type of a ploughshare surface, specialized devices intended to help a plough's casing to bypass obstacles in the form of stones. However, one of the parts of a plough's casing, a landside, has remained unaffected by structural changes. The sliding friction force between a wall of the furrow and a landside leads to the increased traction force of a plough and to increasing the energy intensity of a ploughing unit [1]. It is not possible to abandon a landside because, despite the simplicity of its design, it plays an important role: preventing the displacement of a plough's casing towards the side of the wall of the furrow. The soil response from the wall of the furrow neutralizes the lateral pressure of a layer caused by the non-symmetry of a plough's casings. It was determined that that each landside in the plough PLN-3-35 is exposed to a transverse force of 1 kN, which presses against the wall of the furrow. This leads to the wear of a landside; in addition, the existence of this force gives rise to the soil compaction of the lateral wall of the furrow, thereby breaking its structure, which generally enhances the energy efficiency of the process of cultivation.

Calculating the traction force of a plough mostly employs a Goryachkin formula [2, 3]. The formula takes into consideration the impact on the magnitude of the traction resistance of a plough exerted by its weight G, cultivation depth a, capture width b, soil properties k, and the motions speed of a plough v. However, this formula in its implicit form does not account for the impact on the magnitude for force P exerted by the friction of landsides against the walls of a furrow. However, paper [2] stressed that it is necessary to further refine the individual members of this formula. The sliding friction forces that occurs between landsides and the walls of a furrow were almost neglected; it was mistakenly believed that its magnitude is negligible. Therefore, it is necessary to improve a plough's landside, to search for more efficient, modern working bodies for machines involved in soil cultivation.

There are experimental samples of two- and three-casing ploughs, in which, to reduce the wear resistance of a plough's landsides, each casing was supplemented with the rubber rolls, installed horizontally to the bottom of a furrow, with the possibility to adjust them relative to the wall of the furrow. The data on experimental study indicate that a plough's casing with a supporting rubber roll, installed horizontally, demonstrated traction resistance that was 12 % less than that for a plough's casing with a landside [4].

Paper [5] reported results from a theoretical study into determining the traction resistance of a two-casing plough with a supporting rubber roller. This roller is mounted horizontally to the bottom of a furrow at the second casing and without a landside at the first casing of the plough. The research results have shown that the traction resistance of the improved plough was 9.3 % less than the traction resistance of a standard plough with a landside.

To reduce wear of the most wearable sections in parts of the working bodies of a plough's casings during tilling, it was proposed to make openings in a landside. The axes of the landsides' openings are mounted at an angle in the form of a cut cone [6]. This leads to a decrease in the traction resistance of a plough.

To reduce the energy intensity of the mounted ploughshare PLN-3-35, we installed a furrow wheel after each plough's casing on a leash. Each wheel is pivotally attached to the guide at an angle of α=25–45° to the bottom of the furrow. As the studies have shown, specific fuel consumption with experimental furrow wheels, mounted after each casing of the mounted plough, decreased by 16–21 % [7, 8].

It was proposed to install a drive mechanism in the form of a hydraulic motor on each wheel of a plough. The energy tool is linked through the mechanism of control that enhances performance by increasing the stability of a ploughing unit and reducing the traction effort required to move during operation [9]. Such an mechanism increases the complexity and cost of the structure and, at the same time, reduces reliability.

One of the effective techniques is to abandon a standard landside and replace it with a cylindrical drum. The drum is arranged based on the height of the casing's recess into soil with a vertical axis of rotation, which could reduce the magnitude of friction forces and the cost of fuel and lubricants [10].

Replacing a landside with a flat-rounded element with the vertical axis of rotation in the form of a disk knife, located at the lower part of a bearer, made it possible to reduce the energy consumption by a plough's casing [11]. In order to reduce sliding of the flat-rounded element along the wall of a furrows and to prevent its deflection, it is proposed to apply, at a depth of a ploughshare, a disk knife with notches. A disk knife is set at an angle in the direction of displacement of plough's casing [12]. Due to the magnitude of the transverse force from the side of a removed slice the knife gets deeper into the wall of a furrow at the depth of a ploughshare arrangement. That predetermines the use of negative forces to perform useful work for undercutting a slice of soil [13].

To reduce the energy intensity of a technological process of ploughing, one of the effective techniques is to abandon a standard landside and replace it with a cylindrical drum, which could reduce the magnitude of friction forces. The choice of structural and technological parameters for a cylindrical drum depends on a series of operational and soil-climatic conditions. The derived theoretical dependences make it possible to determine the radius of the drum of a cylindrical landside and the magnitude of leverage for the action of force from a supporting reaction from the side of the wall of a furrow to balance the casing of a plough [14].

In order to prolong the mean time between failures for a standard landside, the mounted ploughs of furrow series PLN-3-35, PLN-4-40, and PLN-5-40 are produced. Atop the back end of landsides are the plates the size of 0.16 m in width, 0.13 m in length, and a thickness of 0.018 m. That makes it possible, in case of its wear, to replace, rather than landsides, these plates only.

Papers [15, 16] report results from experimental studies of a ploughing unit, which established dependences of the largest specific performance of general-purpose ploughs on speed. However, the papers considered the high-speed modes, which are not typical for plowing units, that is, the translational speed of a plough's casing must be within 1–3 m/s.

In a study conducted with the use of a coating, made from fluoroplast, on the working surface of plough's casing, the coating made it possible to reduce the energy intensity of plowing process by 55 % [16]. Application of steel, cast iron, surfacing, ceramic and composite materials, also reduces the energy intensity of plowing process [17].

Plowing the soil is the most energy-intensive operation in plant agriculture. It was determined that reducing the power consumed by a ploughshare, as the most loaded working tool of the plough, could be achieved by oscillations or by changing its parameters [19].

That is, improvement of plough's casings is addressed by a series of scientists, however, there are no comprehensive solutions to the task on constructing a family of plough casings for different conditions of their use. The issue on reducing the traction resistance of working bodies in soil has been also addressed. Summing up the above, one can draw the following conclusions:

– not enough attention has been paid to the influence of a transverse force of pressure acting on the plough's landsides;

– not enough attention has been paid to determining the magnitude for the traction effort of each link in the mechanism of a tractor unit's attachment because designing a strain-gauge mechanism for an attachment requires considerable expenses;

– there are no technical solutions aimed at overcoming such a technological disadvantage, characteristic of a landside, as the existence of a sliding friction force along the wall of a furrow, which leads to the increasing traction effort of a tractor unit, thereby increasing the cost of fuel and lubricants when while tilling the soil.

Therefore, it is a relevant task to resolve a scientific-applied task on determining the impact of structural and operational parameters on energy consumption by a plough.

3. The aim and objectives of the study

The aim of this study is to define directions for reducing the energy intensity of a mounted plough (using the mounted plough PLN-3-35 in an assembly with the tractor MTZ-82 as an example).

To accomplish the aim, the following tasks have been set:

– to conduct an experimental study into determining the dependence of transverse force on the speed and location of a landside;

– to undertake an experimental research into determining the dependence of traction efforts of each link at a tractor's attachment on motion speed;

– to substantiate the ways for reducing the energy intensity of the plough.

4. Materials and methods of the study

4. 1. A measuring system and the arrangement of strain gauges at a landside and on the links in the mechanism of a tractor's attachment

Conducting an experimental study under field conditions aimed at determining the traction characteristics of a plough employs different measuring systems [16, 17, 20, 21].

We applied the system for measuring the dynamics and energy of mobile machines (SMDEMM), which refers to the technical instruments for diagnosing and operational control and can be used in agriculture. The measuring system is intended for determining the kinematic, dynamic, power, and energy characteristics for mobile machines and their elements in field tests [22, 23]. A principal diagram of SMDEMM is shown in Fig. 1.

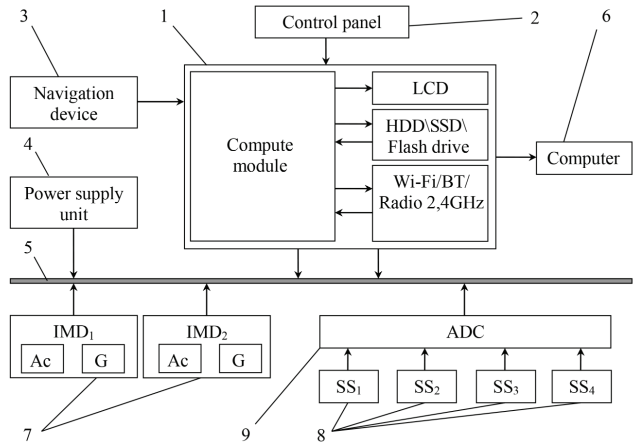

Fig. 1. Principal diagram of the system for measuring the dynamics and energy of mobile machines: 1 — computing module; 2 — control panel; 3 — navigation device; 4 — power supply unit; 5 — CAN data bus; 6 — PC; 7 — inertial measuring device; 8 — strain sensors; 9 — analog-to-digital converter (ADC)

The arrangement of a strain gauge on the links in the attachment's mechanism and at a landside is shown in Fig. 2, 3.

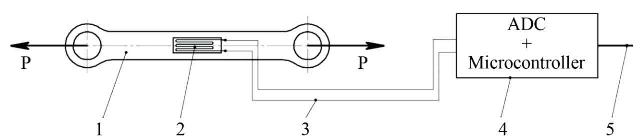

Fig. 2. Arrangement of a strain gauge on the links in the tractor's attachment mechanism: 1 — link; 2 — strain sensor; 3 — signal wires; 4 — ADC and microcontroller; 5 — CAN bus

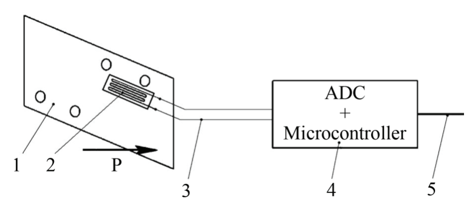

Fig. 3. Arrangement of a strain sensor at a landside: 1 — landside; 2 — strain sensor; 3 — signal wires; 4 — ADC and microcontroller; 5 — CAN bus

Main components in the measuring system (Fig. 1) are a computing module, sensors, and a power supply unit. The computing module is intended for processing, visualization, and storing data acquired from the sensors. The power supply unit enables the measuring system to work autonomously or receive power from an on-board system of the unit.

4. 2. Calibration of strain-gauge equipment

For calibrating the strain sensor mounted on the links in the mechanism of a tractor's attachment and a landside, we used a laboratory bench. The bench makes it possible to consistently connect a calibrated dynamometer to links in the mechanism of a tractor's attachment and a landside, to apply the required load and to maintain it over a long period of time. A model dynamometer that was selected was DPU-50-2, calibrated at NNTs Institute of Metrology (Kharkiv, Ukraine).

The calibration was performed for the strain gauge of a landside, the middle, right, and left links in a tractor's attachment.

The dependence of a loading force on a landside on the codes of ADC is shown in Fig. 4. The dependence of a loading force on the middle link in the mechanism of a tractor's attachment on the codes of ADC is shown in Fig. 5. The dependence of a loading force on the left link in the mechanism of a tractor's attachment on the codes of ADC is shown in Fig. 6. The dependence of a loading force on the right link in the mechanism of a tractor's attachment on the codes of ADC is shown in Fig. 7.

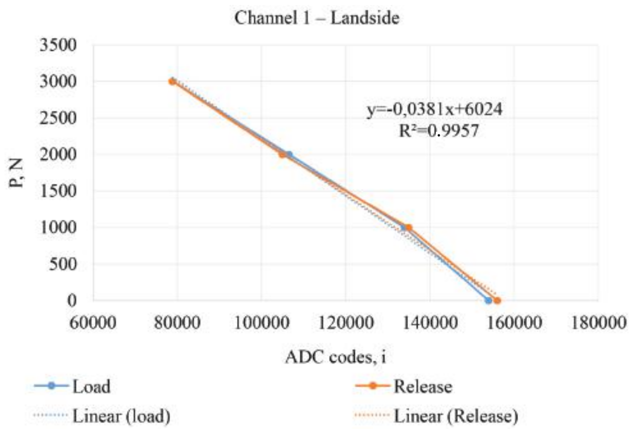

Fig. 4. Dependence of loading force on a landside on the codes of ADC

The dependence of loading force on a landside on the codes of ADC:

$$P_1 = -0.038i + 6024, \quad (1)$$

where i are the codes of ADC.

The coefficient of determination for the strain gauge calibration results on a landside is equal to $R^2=0.9957$, indicating the existence of a dependence and its correctness.

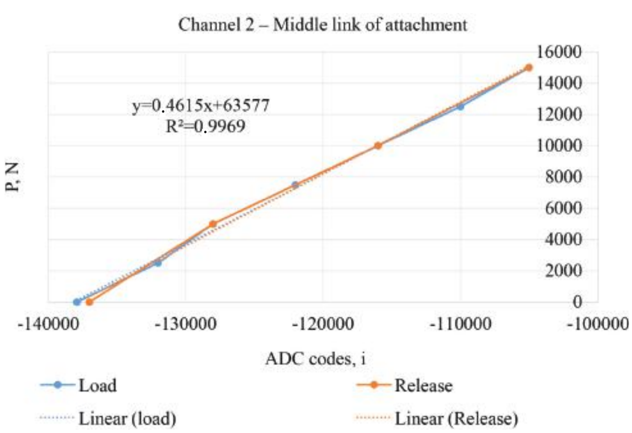

Fig. 5. Dependence of loading force on the middle link in the mechanism of a tractor's attachment on the codes of ADC

For the middle link in the mechanism of a tractor's attachment we have the following dependence of loading force and codes of ADC:

$$P_2 = 0.4615i + 63577. \quad (2)$$

The coefficient of determination is equal to $R^2=0.9969$, which also indicates the existence of a dependence and its correctness.

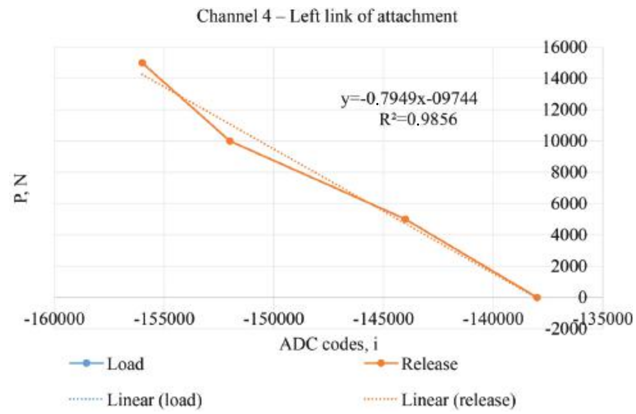

Fig. 6. Dependence of loading force on the left link in the mechanism of a tractor's attachment on the codes of ADC

For the left link in the mechanism of a tractor's attachment we have the following dependence of loading force and codes of ADC:

$$P_4 = -0.7949i - 109744. \quad (3)$$

The coefficient of determination is equal to $R^2=0.983$, indicating the existence of a dependence and its correctness.

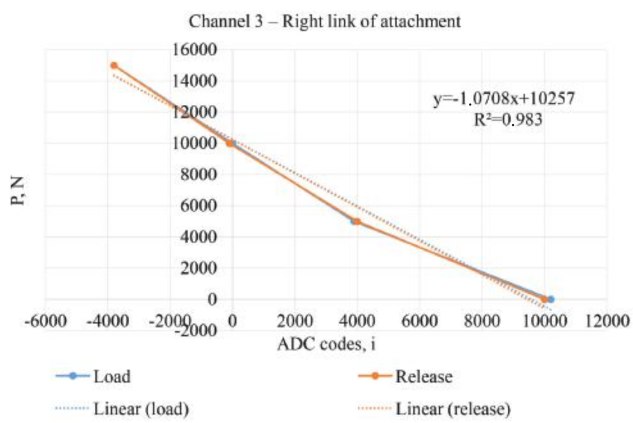

Fig. 7. Dependence of loading force on the right link in the mechanism of a tractor's attachment on the codes of ADC

Finally, we have established the dependence of loading force on the right link in the mechanism of a tractor's attachment and the codes of ADC, which takes the form:

$$P_1 = -1.0708i + 10257. \quad (4)$$

The coefficient of determination is equal to $R^2=0.9856$, indicating the existence of a dependence and its correctness.

The hysteresis for strain gauges does not exceed 5 %.

The study was carried out at the fields of Kharkiv oblast in November 2018. The soil is «plain black soil», the preceding crop is potatoes, the hardness of the soil in layers was, at the surface, 2.71 kPa, at a depth of 0.1 m – 3.03 kPa, and at a depth of 0.2 m the hardness was 4.52 kPa. The moisture content of soil at the surface was 13.2 %, at a depth of 0.1 m – 15.9 %, and at a depth of 0.2 m it amounted to 16.1 %. The depth of ploughing was 0.25 m.

4. 3. Experimental study into determining the transverse force of pressure and the traction effort of a plough

The strain sensor of a plough's landside is connected to the first channel of ADC and hereafter referred to as P_1. The strain sensor at the middle link in the mechanism of an attachment is connected to the second channel of ADC – P_2, the left link – to channel 4 and is denoted as P_4 and the right link – to channel 3 and is denoted as P_3.

The plowing speed for the machine-tractor assembly was chosen to be 1.5 m/s; 2.5 m/s, and 3.0 m/s.

The overall physical appearance of the machine-tractor assembly consisting of the tractor MTZ-82 and the mounted ploughshare PLN-3-35 with the installed measurement system and sensors is shown in Fig. 8.

Fig. 8. Physical appearance of a machine-tractor assembly consisting of the tractor MTZ-82 and the mounted ploughshare PLN-3-35 with the installed measurement system and sensors

The physical appearance of the strain gauges mounted at the right, left, and middle links of the tractor's attachment is shown in Fig. 9–11.

Fig. 9. The physical appearance of the strain gauge installed at the right link of the tractor's attachment

Fig. 10. The physical appearance of the strain gauge installed at the left link of the tractor's attachment

Fig. 11. The physical appearance of the strain gauge installed at the medium link of the tractor's attachment

When conducting the experimental study, it was decided to install at the bearer of a third plough's casing a landside with a strain sensor. The physical appearance is shown in Fig. 12, 13.

Fig. 12. The physical appearance of the tractor MTZ-82 with mounted ploughshare PLN-3-35 and a landside with the strain sensor mounted at the bearer of third casing of the plough

Fig. 13. The side view of a landside with the strain sensor mounted at the bearer of a third casing of the plough

5. Results of experimental research into the magnitude of transverse force of pressure on landsides and the traction efforts of a tractor's attachment

Fig. 14 shows the general form of diagrams for transverse force P_1, which acts on the landside mounted at the bearer of a third casing of the plough.

The diagrams of traction efforts of each tractor's attachment P_2, P_3, and P_4, at motion speed of the tractor assembly 1.5 m/s; 2.5 m/s; 3.0 m/s.

The arrangement scheme of sensors at the machine-tractor assembly when conducting an experimental study of the landside installed at the bearer of a second casing of the plough is shown in Fig. 15.

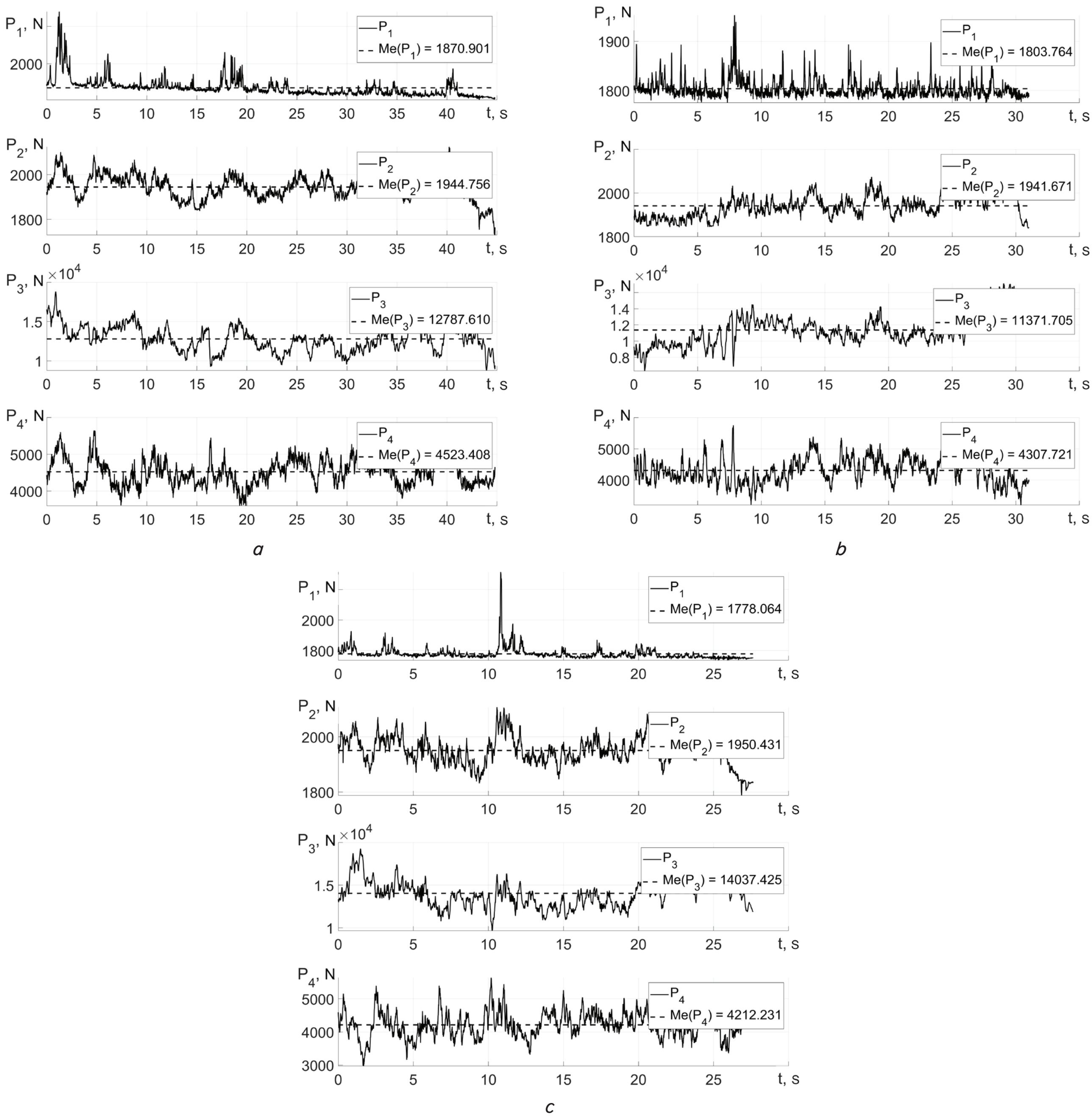

Fig. 14. Diagrams of transverse force P_1, which acts on the landside mounted at the bearer of a third casing of the plough at motion speed of the tractor assembly: *a* – 1.5 m/s; *b* – 2.5 m/s; *c* – 3.0 m/s, and at traction efforts of each link in a tractor's attachment P_2, P_3, and P_4

Fig. 15. The physical appearance of the tractor MTZ-82 with the mounted ploughshare PLN-3-35 and the landside with a strain sensor installed at the bearer of a second casing of the plough

Fig. 16 shows the overall form of diagrams of transverse force P_1, which acts on the landside mounted at the bearer of a second casing of the plough. Diagrams of the traction efforts of each tractor's attachment P_2, P_3, and P_4, at motion speed of the tractor assembly 1.5 m/s; 2.5 m/s; 3.0 m/s.

Diagram of sensors arrangement at the machine-tractor assembly when conducting an experimental study of the landside installed at the bearer of a first casing of the plough is shown in Fig. 17.

Fig. 18 shows the general forms of diagrams for transverse force P_1, which acts on the landside mounted at the bearer of a first casing of the plough. Diagrams of the traction efforts of each tractor's attachment P_2, P_3, and P_4 at motion speed of the tractor assembly 1.5 m/s; 2.5 m/s; 3.0 m/s.

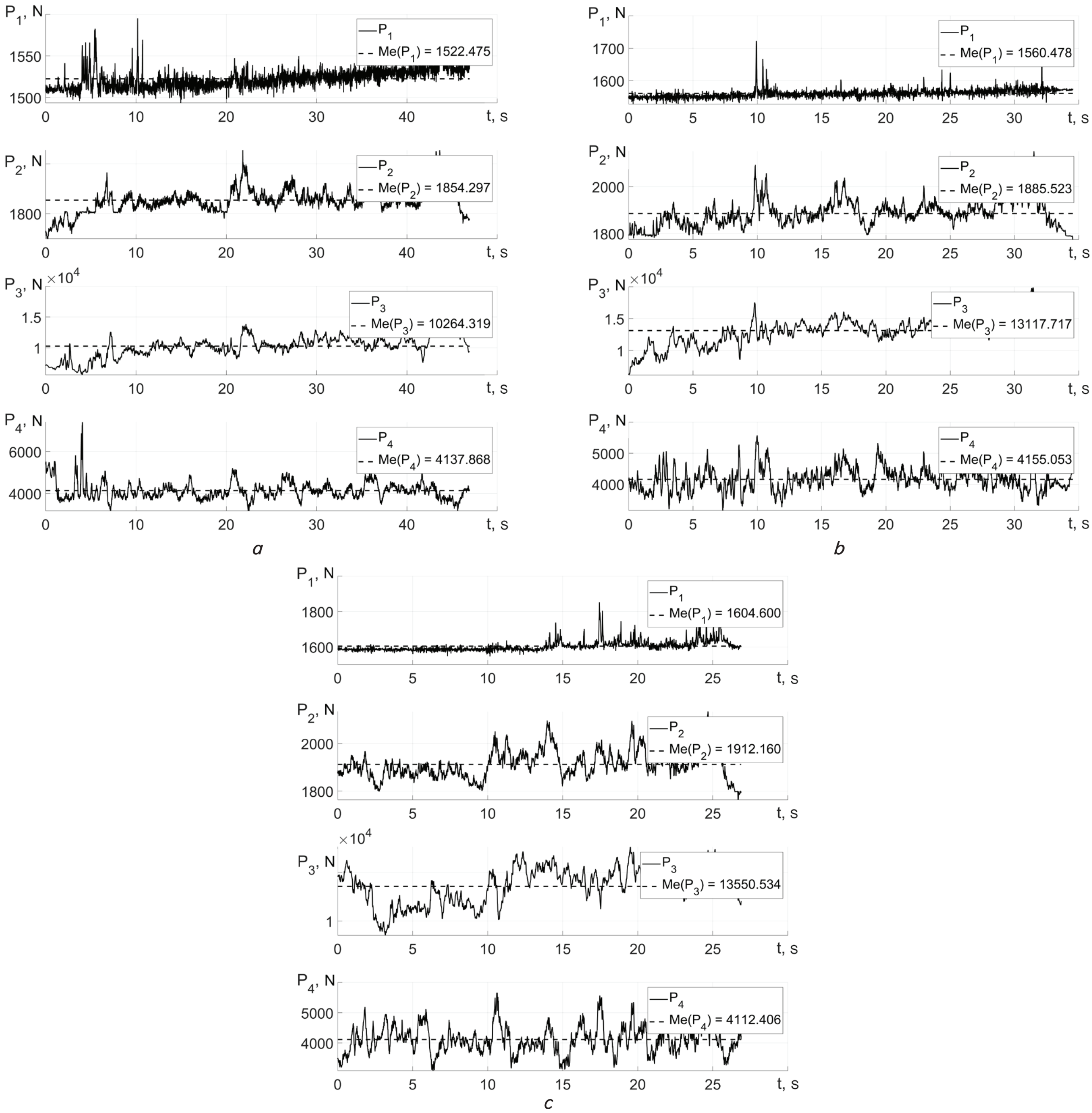

Fig. 16. Diagrams of transverse force P_1, which acts on the landside mounted at the bearer of a second casing of the plough at motion speed of the tractor assembly: *a* — 1.5 m/s; *b* — 2.5 m/s; *c* — 3.0 m/s, and at the traction efforts of each link in a tractor's attachment P_2, P_3, and P_4

Fig. 17. The physical appearance of the tractor assembly with the mounted ploughshare PLN-3-35 and the landside with the strain sensor installed at the bearer of a first casing of the plough

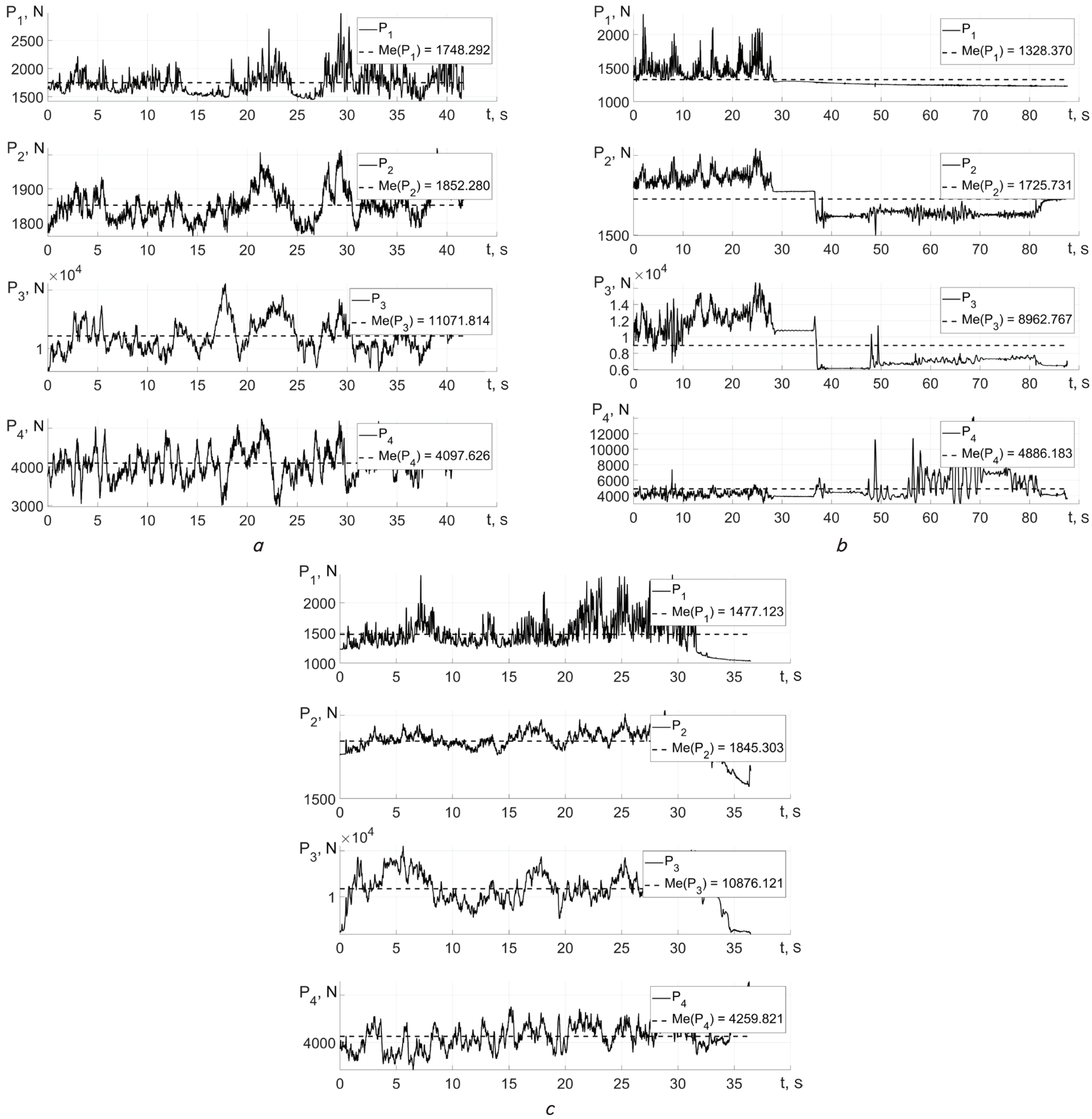

Fig. 18. Diagrams of transverse force P_1, which acts on the landside mounted at the bearer of a first casing of the plough at motion speed of the tractor assembly: *a* – 1.5 m/s; *b* – 2.5 m/s; *c* – 3.0 m/s, and at the traction efforts of each link in a tractor's attachment P_2, P_3, and P_4

5. Discussion of results of experimental study

The experimental study that we conducted has made it possible to define the transverse forces P_1 created by a landside when rotating a slice of soil acting on the landsides mounted at bearers of the casings of the plough PLN-3-35. It was established that depending on the location of the bearer of a plough along a diagonal beam the transverse forces P_1 that act on landsides accept different values and differ considerably from each other. The traction effort of each link in a tractor's attachment P_2, P_3, and P_4 has made it possible to determine which of the links in a tractor's attachment is loaded most, and which one bears the minimum load. The selected motion speeds of the tractor assembly have made it possible to define the dependences for a change in indicators.

It was established that the transverse force of pressure P_1, which acts on each landside of the mounted ploughshare PLN-3-35, differs significantly in its magnitude from each other depending on the motion speed of the tractor assembly. The magnitude of transverse force of pressure P_1 is also affected by the sequence of arrangement of a plough's bearer along a diagonal beam.

Graphical dependence (Fig. 19, position 3) shows that the third landside is exposed to the mean transverse force of pressure P_1 from 1,848–1,871 N. There is a slight decrease in this force with increasing the speed of the tractor assembly.

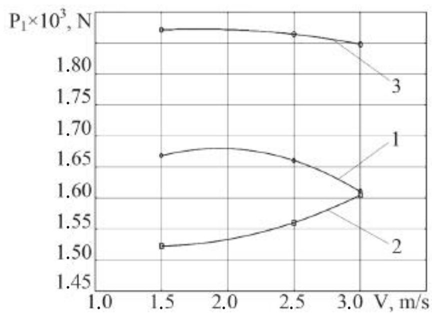

Fig. 19. Mean values for transverse force of pressure P_1, which acts on the landsides mounted at bearers of casings of the mounted ploughshare PLN-3-35 depending on motion speed of the machine-tractor assembly: 1 — the landside installed at the bearer of a first casing of the plough; 2 — the landside installed at the bearer of the middle casing of the plough; 3 — the landside installed at the bearer of a third casing of the plough

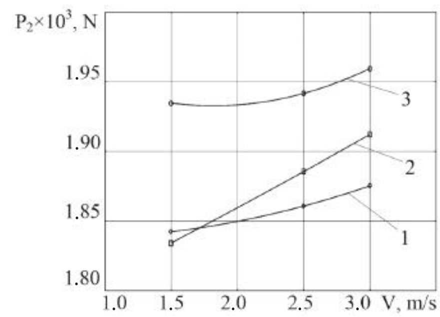

Fig. 20. Mean values for traction effort P_2 that act on the middle link in a tractor's attachment of the mounted ploughshare PLN-3-35 depending on motion speed of the machine-tractor assembly: 1 — the landside installed at the bearer of a first casing of the plough; 2 — the landside installed at the bearer of the middle casing of the plough; 3 — the landside installed at the bearer of a third casing of the plough

However, as shown in Fig. 14, 16, 18, there is an intense impact of the surface of a landside against the wall of a furrow with peak loads of the transverse force of pressure P_1, which exceeds 2,100 N. It is explained by the fact that the third casing of the plough is attached to the diagonal beam of the plough and is at a distance greater than 2 m from the axis of the attachment to the tractor assembly. The tractor assembly in the course of the study is not moving rectilinearly but intensely deviates to the right and to the left of the axis of ploughing; there is an intense rotation of it, which leads to a high-frequency impact of the landside against the wall of the furrow. This contributes to the increased wear of the surface of a landside. The graphical dependence also shows that with an increasing forward speed of the tractor assembly the transverse force of pressure P_1 is reduced by an insignificant magnitude.

The second landside (Fig. 19, position 2) is exposed to transverse force of pressure P_1, which is within 1,522–1,604 N. As shown by the diagrams for P_1, the landside is pressed against the wall of the furrow and rotates both clockwise and counterclockwise in the direction of motion, together with a tractor assembly. This leads to the wear of the surface of a landside. The maximum value for force of pressure P_1 exceeds 1,900 N. The graphical dependence shows that with the increasing forward speed of the tractor assembly the transverse force of pressure P_1 is gradually increasing.

Accordingly, the landside, which is set at the bearer of a first casing of the plough (Fig. 19, position 1) is exposed to the mean transverse force of pressure P_1, which initially accepts a larger value. With an increase in the motion speed of the tractor assembly the force of pressure P_1 decreases, and it is within 1,610–1,668 N.

Since the mounted ploughshare PLN-3-35 is rigidly attached to the tractor's attachment, its first casing follows the translational movement of the tractor. There is a heavy impact of the surface of a landside against the wall of a furrow; the maximum transverse force of pressure P_1 exceeds 2,400 N, which leads to the increased wear of the surface of a landside.

Fig. 20 shows the dependence of traction effort P_2 that acts on the middle link in a tractor's attachment. It was found that the mean value for P_2 is within 1,842–1,959 N, and the maximum value reaches 2,200 N. That is why we cannot neglect this value, one needs to consider it when conducting a study into traction efforts of the mounted ploughshare PLN-3-35.

As shown by Fig. 21, the mean values for traction efforts P_3 that act on the right link in a tractor's attachment make up the main load during ploughing. It was found that the main traction effort is applied to the right link in the mechanism of a tractor's attachment; the mean value is 10,264–14,037 N, and the maximum value for traction effort P_3 reaches 18,570 N. In this case, increasing the forward speed of a tractor assembly increases the traction effort on the right link in the mechanism of a tractor's attachment.

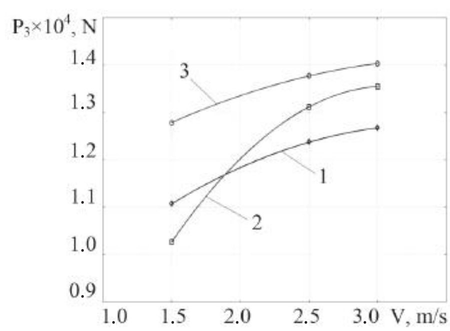

Fig. 21. Mean values for traction efforts P_3 acting on the left link in the tractor's attachment to the ploughshare PLN-3-35 depending on motion speed of the machine-tractor assembly: 1 — the landside installed at the bearer of a first casing of the plough; 2 — the landside installed at the bearer of the middle casing of the plough; 3 — the landside installed at the bearer of a third casing of the plough

During our experimental field study of the mounted ploughshare PLN-3-35 to determine traction efforts P_4 of the left link in the mechanism of a tractor's attachment (Fig. 22), it was found that the left link in a tractor's attachment was almost underloaded. Its mean value is 4,097–4,342 N, and its maximal value amounts to 6,700 N. We can conclude that the left link in a tractor's attachment is almost not loaded.

It is proposed to apply, instead of a standard landside for the mounted ploughshare PLN-3-35, a flat-rounded element in the form of a disk with a hub with a horizontal axis of rotation [24]. The disk converts the sliding friction forces into the rolling friction forces. Application of the disk leads to reducing the energy intensity of the plough by 13–15 %.

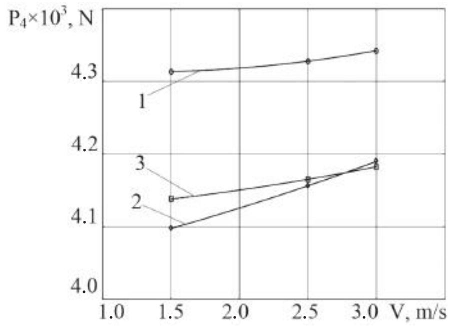

Fig. 22. Mean values for traction efforts P_4, acting on the right link in a tractor's attachment of the mounted ploughshare PLN-3-35, depending on motion speed of the machine-tractor assembly: 1 – the landside installed at the bearer of a first casing of the plough; 2 – the landside installed at the bearer of the middle casing of the plough; 3 – the landside installed at the bearer of a third casing of the plough

6. Conclusions

1. We have applied the system for measuring the dynamics and energy of mobile machines, which is designed for determining the kinematic, dynamic, power, and energy characteristics of mobile machines and their elements under field tests. We have derived the diagrams of values for transverse force P_1 and the traction efforts of each link in a tractor's attachment P_2, P_3, and P_4 with an accuracy of ±2 %.

2. The application of the laboratory bench and the model dynamometer of type DPU-50-2, calibrated at the NNTs Institute of Metrology in line with a certificate for the calibration of the dynamometer, has made it possible to calibrate the strain sensors. The sensors were mounted on the links in a tractor's attachment mechanism and at a landside; hysteresis for strain gauges did not exceed 5 %.

3. Our study of the mounted ploughshare PLN-3-35 has made it possible to establish that the mean value for transverse force of pressure P_1, which acts on the landside installed at the bearer of a first casing of the plough, is 1,610–1,668 N. At the bearer of a second casing of the plough, it is 1,52–1,630 N, and at the bearer of a third casing of the plough it is 1,848–1,870 N. The maximum value for force of pressure P_1 reached at the first landside 2,400 N, at the second – 1,900 N, and at the third – 2,100 N.

4. Based on the research results, it was found that the mean value for the traction effort of each link in the mechanism of attachment of the mounted ploughshare PLN-3-35 differs in magnitude. Traction effort P_2 that acts on the middle link in a tractor's attachment is within 1,842–1,941 N. Traction effort P_3, which acts on the right link in a tractor's attachment is 10,264–14,037 N, and effort P_4 of the left link in the mechanism of attachment is 4,097–4,342 N.

5. One of the reserves for improving the technological indicators and for decreasing the energy intensity of a ploughing assembly is to improve structurally a standard plough's landside. The proposed working body is executed in the form of a flat-rounded element with the shape of a disk with a horizontal axis of rotation, set in a vertical plane in the direction of movement of a tractor assembly. The disk converts the sliding friction forces into the rolling friction forces. Application of the disk leads to reducing the energy intensity of the plough by 13–15 %.

References

1. Novikov V. S. Obespechenie dolgovechnosti rabochih organov pochvoobrabatyvayuschih mashin: monografiya. Moscow: INFRA-M, 2019. 155 p.
2. Yaroshevskiy V. A. Teoreticheskie i eksperimental'nye issledovaniya V. P. Goryachkina v traditsiyah rossiyskoy shkoly mekhaniki // Vestnik FGOU VO MGAU. 2008. Issue 1. P. 10–12.
3. Zaika P. M. Teoriya silskohospodarskykh mashyn. Vol. 1: Ch. 1. Mashyny ta znariaddia dlia obrobitku gruntu. Kharkiv: Oko, 2001. 444 p.
4. Silskohospodarski mashyny: navch. posib. / Voitiuk D. H., Aniskevych L. V., Volianskyi M. S., Martyshko V. M., Humeniuk Yu. O. Kyiv: «Ahroosvita», 2017. 180 p.
5. Belousov S. V. Ploughshare plow with additional disk working bodies // Polythematic Online Scientific Journal of Kuban State Agrarian University. 2016. Issue 115 (01).
6. Korpus pluga: Pat. No. 118637 UA. No. a201802704; declareted: 16.03.2018; published: 11.02.2019, Bul. No. 3.
7. Pluh nachipnyi: Pat. No. 116401 UA. No. a201604514; declareted: 22.04.2016; published: 12.03.2018, Bul. No. 5.
8. Dziuba O. A. Stan pytannia i shliakhy vdoskonalennia lemishnykh nachipnykh pluhiv // Tekhnichnyi servis ahropromyslovoho, lisovoho ta transportnoho kompleksiv. 2018. Issue 11. P. 226–232.
9. Ornyi ahrehat: Pat. No. 118326 UA. No. a201712429; declareted: 14.12.2017; published: 26.12.2018, Bul. No. 24.
10. Korpus pluha: Pat. No. 115184 UA / Dziuba O. A., Fesenko H. V., Dziuba A. I., Merinets N. A. No. a201600130; declareted: 04.01.2016; published: 25.09.2017, Bul. No. 18.
11. Korpus pluha: Pat. No. 114973 UA / Dziuba A. I., Fesenko H. V., Dziuba O. A., Merinets N. A. No. a201512879; declareted: 25.12.2015; published: 28.08.2017, Bul. No. 16.
12. Korpus pluha: Pat. No. 116278 UA. No. a201604515; declareted: 22.04.2016; published: 26.02.2018, Bul. No. 4.
13. Korpus pluha: Pat. No. 117207 UA. No. a201708562; declareted: 21.08.2017; published: 25.06.2018, Bul. No. 12.
14. Theoretical justification of the parameters of a cylindrical plow floor board / Trubilin E. I., Konovalov V. I., Konovalov S. I., Belousov S. V., Movchan E. S. // Polythematic Online Scientific Journal of Kuban State Agrarian University. 2018. Issue 136 (02). doi: https://doi.org/10.21515/1990-4665-136-005

15. Tyagovo-privodnye kombinirovannye pochvoobrabatyvayuschie mashiny: teoriya, raschet, rezul'taty ispytaniya: monografiya / Vetohin V. I. et. al. Kyiv: Feniks, 2009. 265 p.
16. Kozachenko O. V. Problemy resursozberezhennia silskohospodarskykh ahrehativ: monohrafiya / O. V. Blezniuk (Ed.). Kharkiv: KhNTUSH «Tornado», 2008. 269 p.
17. Celik A., Boydas M. G., Altikat S. A Comparison of an experimental plow with a moldboard and a Disk Plow on the Soil Physical Properties // Applied Engineering in Agriculture. 2011. Vol. 27, Issue 2. P. 185–192. doi: https://doi.org/10.13031/2013.36485
18. Analysis of tractive resistance of general plow body elements / Lobachevskiy Ya. P., Komogortsev V. F., Starovoytov S. I., Khramovskikh K. A. // Agricultural machinery and technology. 2016. Issue 2. P. 11–15.
19. Lobachevskiy Ya. P., Starovoytov S. I., Chemisov N. N. Power and technological evaluation of soil cultivating working tool // Agricultural machinery and technology. 2015. Issue 5. P. 10–13.
20. Sahu R. K., Raheman H. Draught Prediction of Agricultural Implements using Reference Tillage Tools in Sandy Clay Loam Soil // Biosystems Engineering. 2006. Vol. 94, Issue 2. P. 275–284. doi: https://doi.org/10.1016/j.biosystemseng.2006.01.015
21. Design and Development of A Three-Point Auto Hitch Dynamometer for An Agricultural Tractor / Kheiralla A. F., Yahya A., Zohadie M., Ishak W. // ASEAN Journal on Science and Technology for Development. 2017. Vol. 20, Issue 3&4. P. 271. doi: https://doi.org/10.29037/ajstd.355
22. Antoshchenkov R. V. Dynamika ta enerhetyka rukhu bahatoelementnykh mashynno-traktornykh ahrehativ: monohrafiya. Kharkiv: KhNTUSH, «Miskdruk», 2017. 244 p.
23. Antoschenkov R. V. Izmeritel'naya sistema dinamicheskih i energeticheskih parametrov traktorov i mashinno-traktornyh agregatov // Mezhdunarodniy nauchniy, nauchno prilozhniy i informatsionniy zhurnal «Mekhanizatsiya na zemedelieto». 2015. Issue 12. P. 9–11.
24. Korpus pluga: Pat. No. 131846 UA. No. a201802549; declareted: 14.03.2018; published: 11.02.2019, Bul. No. 3.