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DEVELOPMENT OF A LABORATORY TEST RIG FOR STUDYING ACTIVELY-DRIVEN TRAILER WHEELS OF A TRACTOR-TRAILER UNIT

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Tractor-trailer units (TTU) equipped with actively-driven trailer wheels represent significant potential for modern agricultural applications. However, their widespread scientific study and industrial implementation remain limited due to insufficient understanding of the actively-driven wheel-supporting surface interaction. The research purpose is to substantiate the fundamental principles for enhancing the off-road mobility of tractor-trailer unit. This paper presents the results of development of laboratory test rig for experimental investigation on substantiation of actively-driven (trailer) wheel rotation modes. The engineering documentation for the laboratory test rig was developed in accordance with technical design requirements in compliance with Unified System for Design Documentation Standards using the KOMPAS-3D software. The research has yielded a mathematical expression for defining the operational range of coefficient of kinematic mode of wheel rotation during laboratory test rig testing studying. Based on the expression data and functional relationships between the coefficient of kinematic mode of wheel rotation and the number of teeth on change gear (gear ratio) were obtained. Based on the research results, the gear ratios corresponding to the investigated range of the kinematic rotation mode coefficient of the tested wheel were determined. Thus, the developed laboratory test rig enables to conduct experimental studies of the performance of the running wheels of an actively-driven trailer, in order to substantiate the principles of improving the off-road mobility of tractor–trailer units.

Key words: *laboratory test rig, wheel, trailer, active drive, kinematic mode, tractor-trailer unit.*

БЕЛСЕНДІ ЖЕТЕКТІ ЖҮЙЕСІ БАР ТРАКТОР-ТРАНСПОРТТЫҚ АГРЕГАТ ТІРКЕМЕСІНІҢ ДӨҢГЕЛЕКТЕРІН ЗЕРТТЕУГЕ АРНАЛҒАН ЗЕРТХАНАЛЫҚ ҚОНДЫРҒЫНЫ ӘЗІРЛЕУ

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Белсенді жетек жүйесі бар трактор-транспорттық агрегаттар (ТТА) қазіргі ауыл шаруашылығы үшін болашағы зор техника түрі болып табылады. Алайда, белсенді жетек жүйесі бар дөңгелектердің тірек бетімен өзара әрекеттесу үдерісі туралы білімнің жеткіліксіздігі бұл техниканың ғылыми тұрғыда кеңінен зерттелуін және өндірісте қолданылуын тежейді. Жұмыстың мақсаты – трактор-транспорттық агрегаттардың өтімдігін артыру принципін негіздеу. Бұл мақалада белсенді жетекті дөңгелектердің айналу режимдерін негіздеу бойынша тәжірибелік зерттеулерге арналған зертханалық қондырғыны әзірлеу жұмыстарының нәтижелері келтірілген. Зертханалық қондырғыны жасауға құрылымдық құжаттама ЖҚБЖ талаптарына сәйкес КОМПАС-3D бағдарламасын пайдалана отырып әзірленді. Зертхалалық қондырғыда зерттеу жүргізу кезінде дөңгелектің айналуының кинематикалық режимі коэффициентінің қажетті диапазонын анықтауға арналған математикалық өрнек алынды. Алынған өрнек негізінде қондырғы жетегінің ауыстырмалы жұлдызшаларындағы тістер санына (беріліс қатынасына) байланысты дөңгелектің айналу кинематикалық режимі коэффициентінің тәуелділігі туралы деректер анықталды. Осылайша, әзірленген зертханалық қондырғы тракторлы-транспорттық агрегаттардың (ТТА) өтімділігін арттыру принципін *негіздеу үшін тіркеменің пәрменді жетекті жүріс дөңгелегінің жұмысын тәжірибелік зерттеулерін жүргізуге мүмкіндік береді.*

Түйінді сөздер: *зертханалық қондырғы, дөңгелек, тіркеме, белсенді жетек, кинематикалық режим, тракторлы-транспорттық агрегат.*

РАЗРАБОТКА ЛАБОРАТОРНОЙ УСТАНОВКИ ДЛЯ ИССЛЕДОВАНИЯ КОЛЕС ПРИЦЕПА ТРАКТОРНО-ТРАСПОРТНОГО АГРЕГАТА С АКТИВНЫМ ПРИВОДОМ

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Тракторно-транспортные агрегаты (ТТА) с активным приводом колес прицепов являются перспективными для современного сельского хозяйства. Однако, широкое научное внимание и производственное применение сдерживается отсутствием знаний о процессе взаимодействия опорной поверхности колес с активным приводом. Цель работы – обоснование принципов повышения проходимости тракторно-транспортного агрегата. В статье представлены результаты разработки лабораторной установки для проведения экспериментальных исследований по обоснованию режимов вращения колеса (прицепа) с активным приводом. Разработка конструкторской документации на изготовление лабораторной установки выполнялась согласно техническим требованиям по проектированию, в соответствии с требованиями ЕСКД, с использованием программы КОМПАС-3D. Получено математическое выражение для определения необходимого диапазона коэффициента кинематического режима вращения колеса при проведении исследований на лабораторной установке. На основе выражения получены данные о зависимости коэффициента кинематического режима вращения колеса от количества зубьев сменных звездочек передач привода установки (передаточного отношения). По результатам исследований установлены передачи, соответствующие исследуемому диапазону коэффициента кинематического режима вращения исследуемого колеса. Таким образом, разработанная лабораторная установка позволяет проводить экспериментальные исследования функционирования ходовых колес прицепа с активным приводом для обоснования принципов повышения проходимости тракторно-транспортных агрегатов.

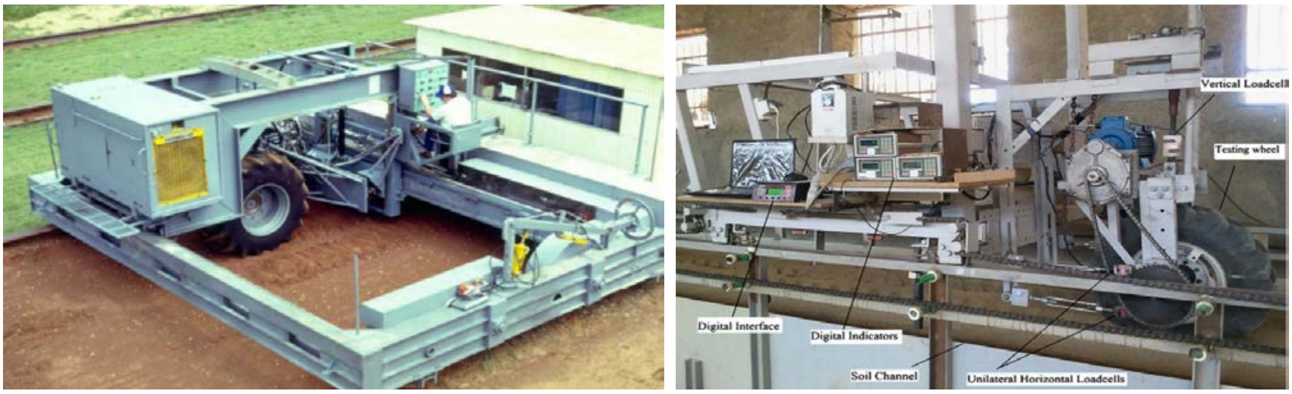
Ключевые слова: *лабораторная установка, колесо, прицеп, активный привод, кинематический режим, тракторно-транспортный агрегат.*

Introduction. Tractor-trailer units (TTU) with actively driven trailer wheels are promising for modern agriculture. They allow improving the traction-coupling properties of the unit, reducing tractor wheel slippage, increasing trailer load capacity and travel speed of the unit [1, p.6; 2, p.46; 3, p.216; 4, p.45; 5, p.102]. However, their widespread scientific study and industrial implementation remain limited due to the lack of knowledge about the process of actively-driven wheels with the supporting surface interaction.

The study of any objects in agricultural engineering science, as a rule, is closely related to conducting experiments. To study the interaction of wheels with the supporting surface, it is necessary to conduct both field and laboratory experimental studies using special experimental facilities. At the same time, the use of laboratory facility allows conducting experiments under controlled conditions. The main components include a soil bin filled with material (soil, sand, etc.), a movable carriage for mounting the test wheel, a drive system, mechanisms for adjusting process parameters, an energy source, equipment for preparing soil conditions before experiments and measuring instruments.

The study of agricultural machinery wheels' interaction with the soil under laboratory conditions has been the subject of research by many scientists, Figure 1.

Bailey A.C. et al. conducted experiments to study the changes in the soil stress state caused by the tractor wheel operation at different levels of dynamic loads and inflation pressures [6, p.2]. Wood R.K. et al. investigated the effects of dynamic load on the tractive thrust components along the tire-soil contact zones in loose and compacted soil conditions at different levels of dynamic loads [7, p.44]. Way T.R. et al. examined the effects of tractor wheel tire aspect ratio on soil stresses and rut depths for two tractor tires (580/70R38 and 650/75R32) with slightly different aspect ratios of 0.756 and 0.804 respectively at different dynamic loads and inflation pressures on a sandy and clay loams with loose soil above the hardpan beneath the centerlines and edges of the wheel tires. [8, p.872]. Way T.R. and Kishimoto T. measured the tire-soil interface pressures of a tractor drive tire on structured and loose soils at different inflated combinations of dynamic load and inflation pressures and applied the results in estimating the tire footprint areas in contact for the operating tires [9, p.376]. Roozbahani A. et al. designed inside soil bin with single-wheel tester and conducted a study to measure and estimate the performance parameters of agricultural wheels [10, p.159]. The wheel was driven by an electric motor and a power bolt was used to apply vertical load on this wheel. Parameters that could be measured by this system included draft force, tire sinkage, wheel contact area, soil stress at different depths and traction force. Antille D.L. et al. studied the changes in soil bulk density from soil displacement data produced by a range of harvester tires (680/85R32, 800/65R32, and 900/60R32) with a vertical load of 10.5 tons and inflation pressures in the range 0.19-0.25 MPa to provide a valuable index for tire selection, in a soil bin test rig using a sandy loam soil maintained at 10% moisture content [11, p.1684]. Taghavifar H. and Mardani A. conducted an analysis of energy dissipation of run-off-road wheeled vehicles in a controlled environment of a soil bin test rig [12, p.974]. Taghavifar H. et al. conducted a multi-criteria optimization research using a soil bin test rig to study the energy waste of off-road vehicles [13, c.763]. Yahya M. et al. (2007) developed an indoor soil bin test rig for traction investigations with data acquisition system to receive in real time the measured signals of forces, tire sinkage, tire velocity and travel speed [14, c.295]. Taghavifar H. and Mardani A. conducted a study on the potential of a functional image processing technique for the measurements of contact area and contact pressure of a radial ply tire in a soil bin test rig [15, c.4039].



a) b)

a – for outdoor conditions (Way T.R. et al.); b – for indoor conditions (Taghavifar H. et al.)

Figure 1 – Experimental facilities used for the study of agricultural wheels

In recent times, terramechanics is also being applied in the study of mobility and control of wheeled mobile robots designed for movement on soft and deformable soils on Earth and other planetary bodies. Many researchers in this field use single-wheel and other forms of test beds for wheeled mobile robots similar to soil bin laboratory test rigs [16, c.35; 17. c.80]. In doing so, with most of the control and data acquisition systems attached to the single-wheel systems or embedded in the robots unlike the conventional soil bins.

Thus, to study actively-driven trailer wheels, it is necessary to develop a special laboratory test rig that accounts for adjustable parameters and their operating modes. This determines the relevance for agriculture and the significant importance for the development of agricultural engineering science.

The research purpose is to substantiate the fundamental principles for enhancing the off-road mobility of tractor-trailer unit.

Tasks:

1) Development of a laboratory test rig;

2) Substantiation of the range of coefficient of kinematic mode of wheel rotation.

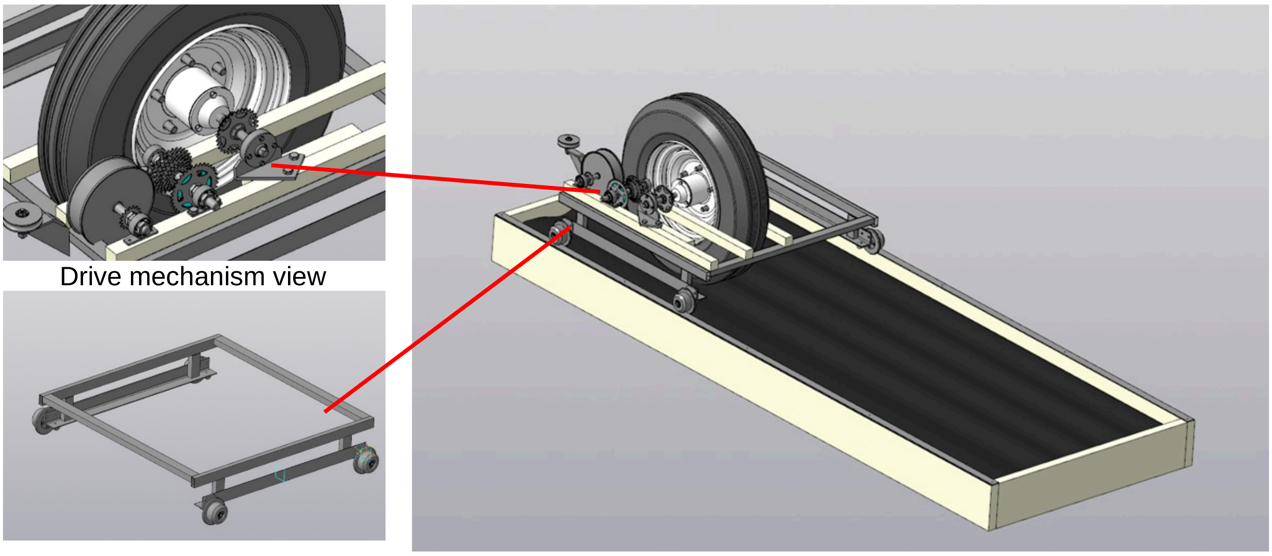
Materials and Methods. The development of engineering documentation for manufacturing the laboratory test rig was carried out in accordance with technical design requirements following the Unified System for Design Documentation Standards using the KOMPAS-3D software.

For the study, a standard agricultural wheel with radius R=0.3 m was selected. The coefficient of kinematic mode of wheel rotation λ varies in the range from 0.6 to 1.4 with an increment of 0.2.

Figure 2 shows a 3D model of the laboratory test rig for conducting experimental studies. Figure 3 presents the kinematic diagram of the developed laboratory test rig.

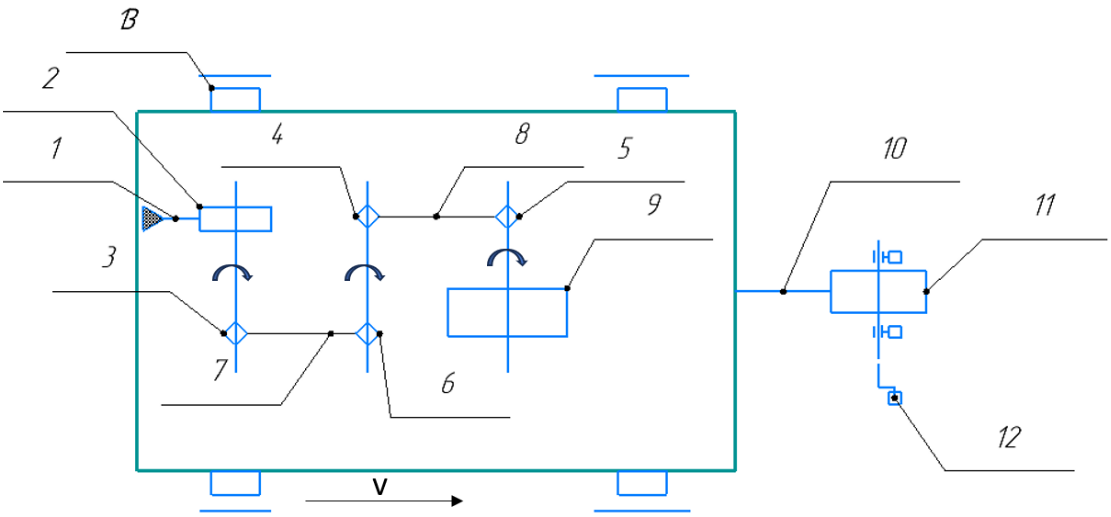
The laboratory test rig includes: a soil bin simulating various road conditions, enabling tests on different surface types, a trailer carriage with an active drive system regulating wheel rotation modes. This allows investigating the effect of different technological adjustments on mobility.

The carriage, designed as a rectangular frame, provides stability and structural strength of construction, active drive system integrated into the trailer design for efficient traction force transmission.



Carriage view General view of the soil bin

Figure 2 – 3D model of laboratory test rig



1, 10 – cables, 2 – unwinding drum, 3, 4, 5, 6 – sprocket blocks, 7, 8 – chain drives, 9 – wheel, 11 – winding drum, 12 – drive mechanism handle, 13 – sliding bearings

Figure 3 – Kinematic diagram of the laboratory test rig drive system

The technological process of the laboratory test rig operation occurs as follows. The operation begins with the rotation of handle 12, connected to the winding drum 11, onto which cable 10 is wound. As the cable is wound, the trailer carriage begins to move along the soil bin. The movement is smooth and controllable due to the cable tension, which transmits force from the drum to the trailer carriage. To reduce friction and enhance stability, sliding bearings 13 are used. This helps minimize component wear and ensures smooth movement.

Cable tension is one of the key factors affecting system stability and controllability. It ensures reliable force transmission and allows smooth control of the trailer carriage's speed and direction. This enables simulation of various road and soil conditions that are important for testing.

Simultaneously with the rotation of winding drum 11, unwinding drum 2 begins to operate. It contains a pre-wound cable 1, fixed at one end to a stationary shank. This maintains constant tension in the system and prevents oscillations that could affect experimental accuracy. The unwinding drum transmits rotation through the chain drive: first to sprocket 3, then to sprocket 4, and subsequently through intermediate components to the test wheel 9.

The chain mechanism plays a crucial role in controlling the laboratory test rig's operating components. The sprockets and chains are designed to transmit rotation with maximum precision and synchronization. This is necessary for accurate control of the rotational speed and force of wheel 9, which interacts with various soil types. This allows investigation of trailer mobility in sand, clay, hard or soft surface conditions.

Wheel 9 is one of the main elements involved in analyzing the trailer's interaction with the supporting surface. It features an active drive with adjustable rotation speed capability. This enables comprehensive testing and simulation of real operating conditions.

The chain mechanism plays a crucial role in controlling the working components of the laboratory test rig. The sprockets and chains are designed to ensure maximum precision and synchronization in power transmission. This is essential for accurate control of both rotational speed and torque of wheel 9, which interacts with various soil types. This capability enables comprehensive investigation of trailer mobility across different surfaces including sand, clay, and both hard and soft terrain.

Wheel 9 serves as one of the key elements in analyzing the trailer's interaction with the supporting surface. Featuring an active drive system with adjustable rotation speed, it permits exhaustive testing and realistic simulation of actual operating conditions.

Results and Discussion. Technical design requirements and engineering documentation have been developed, enabling successful manufacture of the laboratory test rig comprising a trailer carriage with actively-driven wheel (Figure 4).

Figure 4 – Laboratory test rig with actively-driven wheel

The soil bin consists of a sturdy box with metal bars that provide rigidity and stability during testing.

The trailer carriage of the laboratory test rig is a mobile structure with metal wheels equipped with bearings, enabling its movement along the soil bin.

The overall dimensions of the laboratory test rig (1800×800×600 mm), as specified in the drawings, were maintained with a tolerance of ±5 mm. All welded joints were executed in compliance with the technical requirements indicated in the drawings. Particular attention was given to the assembly of the sliding bearing mounting unit, as its precision directly affects the performance of the entire drive system.

The laboratory test rig's adjustable parameters make it a versatile and multifunctional platform for research and testing. For this purpose, the laboratory test rig is equipped with mechanisms for regulating technological parameters and operating modes, allowing adjustments to:

- Chain drive gear ratios;
- Carriage movement speed;
- Wheel rotation speed;
- Coefficient of kinematic mode of wheel rotation;
- Wheel parameters and geometry;
- Wheel camber and toe angles;
- Vertical load on the wheel;
- Road surface type;
- Physical and mechanical properties of the supporting surface.

The carriage features a drive mechanism whose adjustment system enables modification of chain drive gear ratios, carriage movement speed, wheel rotation speed, and coefficient of kinematic mode of wheel rotation. This allows investigation and simulation of different motion modes (slippage, skidding).

The laboratory test rig includes interchangeable components for adapting to different agricultural wheels. This enables modification of wheel parameters and geometry (type, radius, width, tread profile, tire pressure, etc.), as well as camber and toe angles, and study of their effect on mobility.

The soil bin of the laboratory test rig permits changes to road surface type (soil, sand, mud, snow, etc.) as well as physical and mechanical properties of the supporting surface (moisture content, hardness, density, etc.). This capability allows simulation of various road conditions, enabling experiments under circumstances closely approximating real application conditions.

The ability to apply different vertical loads on the wheel expands the research scope. Jointly, these features make the laboratory test rig multifunctional and capable of conducting diverse tests within the framework of motion mechanics research, wheel-soil interaction studies and force measurement.

Overall, the laboratory test rig provides precise control over all research and testing stages – from carriage launch to analysis of its behavior under various investigated conditions. This is valuable not only for educational and research purposes, but also for further improvements in actively-driven trailer designs, enhancing their mobility and effectiveness in real application conditions.

As shown in the kinematic diagram (Figure 2), force transmission occurs sequentially: Manual drive → Cable transmission → Drum → Chain drive → Driven wheel.

Coefficient of kinematic mode of test wheel rotation is characterized by the ratio of its circumferential velocity to translational velocity:

$$\lambda = V_o / V_e. \quad (1)$$

where, V_0 – circumferential velocity of the wheel;

V_e – translational velocity of the wheel.

Depending on the value of λ, the following modes of wheel rotation are distinguished:

- $\lambda<1$: the wheel moves with slippage (unpowered mode);
- $\lambda>1$: the wheel moves with skidding (powered mode);
- $\lambda=1$: the wheel moves without slippage or skidding (powered mode).

The translational and circumferential velocities of the test wheel are adjusted by changing the gear ratio using a set of interchangeable sprockets of the drive mechanism.

To determine the coefficient of kinematic mode of wheel rotation, the gear ratio of all sprockets in the drive mechanism is calculated. The numerical values of sprocket teeth count used for calculating the coefficient of kinematic mode are shown in Table 1.

The coefficient of kinematic mode of rotation is preliminarily determined by the formula according to the kinematic diagram of the laboratory test rig's drive mechanism:

$$\lambda = (z_{p\,б} \cdot r_p \cdot z_2) / (z_p \cdot r_{p\,б} \cdot z_1), \quad (2)$$

where: $z_{p\,б}$ – number of teeth on the unwinding drum shaft sprocket;

z_p – number of teeth on the wheel shaft sprocket;

$r_{p\,б}$ – radius of the unwinding drum, m ($r_{p\,б}$=0.11 m);

r_p – wheel radius, m;

z_1, z_2 – number of teeth on corresponding sprockets.

Thus, we obtain the formula for determining the coefficient of kinematic mode of actively-driven wheel rotation installed on the laboratory test rig for research purposes. It should be noted that increasing the wheel radius leads to an increase in the coefficient of kinematic mode of rotation.

Table 1 – Number of teeth on the set of drive mechanism sprockets

Gear No.	Number of teeth on the sprockets			
	Drive shaft (wheel axis)	Intermediate axis	Intermediate axis	Drive shaft (drum axis)
	position 5	position 4	position 6	position 7
1	14	14	48	15
2	16	16	–	–
3	18	18	–	–
4	22	20	–	–
5	24	22	–	–
6	28	24	–	–
7	–	28	–	–

The investigated range of the coefficient of kinematic mode of wheel rotation is 1.0≤λ≤2.0. This range was selected based on the criterion of improving the unit's mobility with minimal energy consumption.

Table 2 presents the calculation results using formula (2).

Table 2 – Operating modes of the laboratory test rig for investigating the actively-driven wheel

$Z_б$	Kinematic mode **λ**					
	gears					
	1	2	3	4	5	6
	Z_p=14	Z_p=16	Z_p=18	Z_p=22	Z_p=24	Z_p=28
14	0.85	0.97	1.10	1.34	1.46	1.70
16	0.75	0.85	0.96	1.17	1.28	1.49
18	0.66	0.76	0.85	1.04	1.14	1.33
20	0.60	0.68	0.77	0.97	1.02	1.19
22	0.54	0.62	0.70	0.85	0.93	1.08
24	0.50	0.57	0.64	0.78	0.85	0.99
28	0.43	0.49	0.55	0.67	0.73	0.85

Based on the calculation results, samples of rotation modes corresponding and not corresponding to the investigated range were selected. In the table, modes within the range are marked in green, while those outsides are marked in red.

A graph of the dependencies of the coefficient of kinematic mode of rotation λ on the number of teeth of the interchangeable drive sprockets $Z_б/Z_p$ was plotted (Figure 5).

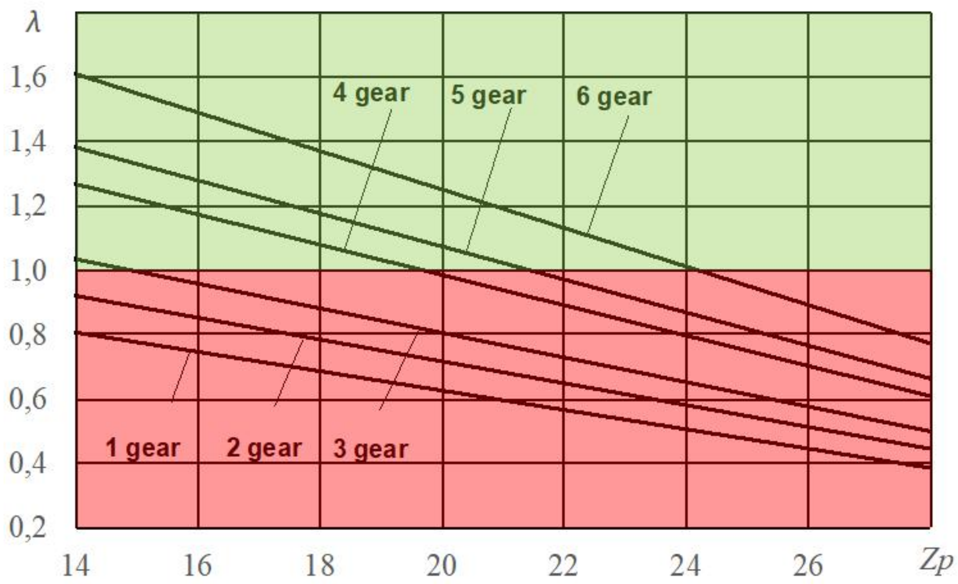


Figure 5 – Dependencies of the coefficient of kinematic mode of wheel rotation λ on the number of teeth of the interchangeable drive sprockets $Z_б/Z_p$

On the graph, the area corresponding to the investigated range of kinematic modes is highlighted in green, while the non-corresponding area is in red.

It was revealed that for a wheel with radius R_p=0.3 m, rotation modes within the investigated range are only available in gears 4-6. Nearly all options in gears 1-3 fall outside the investigated range, with kinematic mode of rotation values below λ<1.0.

Thus, the research results yielded values corresponding to the investigated range of the coefficient of kinematic mode of actively-driven wheel rotation. Experimental studies using the developed laboratory test rig will continue.

Conclusion. Tractor-trailer units (TTU) with actively-driven trailer wheels show promise in modern agriculture by improving mobility.

This work enabled the creation of a laboratory test rig for experimental investigation of actively-driven trailer wheels – a significant step in developing high-mobility tractor-trailer units (TTU). The developed facility offers several advantages: adjustable wheel parameters and operation modes, simulation of various supporting surface conditions, measurement of force characteristics, etc. These features ensure experiments closely approximate real operating conditions.

An expression has been obtained for selecting the required coefficient of kinematic mode of actively-driven wheel rotation during investigations on the laboratory test rig. The dependencies of the coefficient of kinematic mode of rotation on the number of teeth of interchangeable sprockets in the laboratory test rig's drive mechanism (gear ratio) have been established. The research has identified transmission configurations corresponding to the investigated range of the coefficient of kinematic mode of test wheel rotation.

The developed laboratory test rig serves as a reliable foundation for further experiments aimed at substantiating and selecting parameters and operating modes for actively-driven wheels. These parameters will ensure enhanced mobility of tractor-trailer units (TTU) with minimal energy expenditure, consequently improving the operational efficiency of TTU.

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СЕЗОННАЯ ИЗМЕНЧИВОСТЬ ГЕМАТОЛОГИЧЕСКИХ И БИОХИМИЧЕСКИХ ПОКАЗАТЕЛЕЙ КРОВИ БЫЧКОВ РАЗЛИЧНЫХ ГЕНОТИПОВ

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В условиях резко континентального климата исследование физиологических механизмов адаптации молодняка мясного скота приобретает особую актуальность, поскольку гематологические и биохимические показатели крови служат чувствительными индикаторами реакции организма на сезонные изменения кормления и содержания. Цель работы заключалась в оценке сезонной изменчивости основных показателей крови и сравнении адаптационных особенностей молодняка разных генотипов. Объектами исследования были бычки казахской белоголовой породы и помеси первого поколения с симментальской, лимузинской и аулиекольской породами. Методы включали определение гематологических показателей, активности сывороточных ферментов, минерального состава, витамина А и белковых фракций в зимний и летний периоды.

Установлено, что сезон достоверно влияет ($p<0,05$) на большинство параметров: летом отмечалось усиление обменных процессов, проявляющееся повышением трансаминаз, уровня альбуми-