UDC 62-614
DOI: 10.31471/1993-9868-2024-1(41)-105-117

ENERGY EFFICIENCY INCREASE IN TRANSMISSION UNITS OF TECHNOLOGICAL TRANSPORT

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Стаття спрямована на зниження втрат енергії в трансмісійних агрегатах нафтогазового технологічного транспорту. Були проаналізовані основні напрямки зі скорочення енергоспоживання нафтогазового технологічного транспорту. Проведений аналіз особливостей конструкції трансмісій установок нафтогазового технологічного транспорту. Виконані дослідження температурного режиму в трансмісійних агрегатах, в'язкісних та температурних характеристик сучасних трансмісійних олив. Був запропонований метод підтримання оптимального температурного режиму та швидкого прогріву в трансмісійних агрегатах нафтогазового технологічного транспорту за рахунок використання теплоти відхідних газів двигунів. Досліджена типова механічна трансмісія мобільного підйомного агрегату для ремонту нафтогазових свердловин на колісному шасі. Наведені засоби експериментальних досліджень та методика дослідження енергоефективності трансмісій нафтогазового технологічного транспорту. Виконані теоретичні та експериментальні дослідження реалізації запропонованого методу зниження втрат енергії в агрегатах трансмісії нафтогазового технологічного транспорту. Встановлені залежності зміни температур трансмісійної оливи в коробці перемикання передач нафтогазового технологічного транспорту при різних режимах обертання первинного валу коробок передач. Одержана залежність втрат потужності в коробці передач мобільного агрегату моделі АОРС-60 в залежності від сорту трансмісійної оливи та температури. Наведені результати розрахунків витрат палива в коробці передач мобільного агрегату моделі АОРС-60 за різних температур трансмісійної оливи та з різними силовими приводами.

Ключові слова: нафтогазовий технологічний транспорт, трансмісійний агрегат, коробка перемикання передач, дизельний двигун, утилізація теплоти, питома витрата палива.

The article is aimed at reducing energy losses in transmission units of oil and gas technological transport. The main directions for reducing the energy consumption of oil and gas technological transport were analyzed. The analysis of the features of the design of transmissions of oil and gas technological transport installations was carried out. Conducted studies of the temperature regime in transmission units, viscosity and temperature characteristics of modern transmission oils. A method of maintaining the optimal temperature regime and rapid warm-up in the transmission units of the oil and gas technological transport due to the use of the heat of the exhaust gases of the engines was proposed. A typical mechanical transmission of a mobile lifting unit for the repair of oil and gas wells on a wheeled chassis was studied. The means of experimental research and the method of researching the energy efficiency of transmissions of oil and gas technological transport are given. Theoretical and experimental studies of the implementation of the proposed method of reducing energy losses in the transmission units of oil and gas technological transport were carried out. The dependences of the temperature changes of the transmission oil in the gearbox of the oil and gas technological transport at different modes of rotation of the primary shaft of the gearboxes are established. The dependence of power losses in the gearbox of the mobile unit of the AORS-60 model depending on the type of transmission oil and temperature was obtained. The results of fuel consumption calculations in the gearbox of the AORS-60 model mobile unit at different transmission oil temperatures and with different power drives are presented.

Key words: oil and gas technological transport, transmission unit, gearbox, diesel engine, heat utilization, specific fuel consumption.

INTRODUCTION

The oil and gas industry includes numerous production divisions of technological transport. Oil and gas technological transport includes a significant nomenclature of installations: for hydraulic fracturing, washing and sand mixing installations; for drilling and repairing wells; mobile compressors; cementing and cement mixing units; for maintenance and repair of oil and gas industry equipment; steam generators; for adjustment and installation of oil and gas industry equipment, lubrication of rocking machines; for repair and construction of gas and oil pipelines and many other types and models. In terms of its number, oil and gas technology transport outnumbers all other types of transport in other industries. Therefore, the problem of reducing energy consumption for oil and gas technological transport, in particular reducing energy consumption in the transmissions of lifting installations, deserves special attention.

ANALYSIS OF MODERN RESEARCH AND PUBLICATIONS

Improving energy efficiency is one of the main priorities of Ukraine. In 2017 Ukraine approved the "New Energy Strategy of Ukraine until 2035: security, energy efficiency, competitiveness" – this is the main document that defines the strategic guidelines for the development of the country's fuel and energy complex for the period until 2035. According to this normative act, that the share of imported components in the structure of the country's total primary energy supply will decrease to less than 33 % in 2025-2035, in particular thanks to the improvement of energy efficiency and energy saving in compliance with modern environmental standards and the widespread development of renewable energy sources. The new energy strategy of the state contains three main stages, the main result of which should be a reduction of the energy intensity of GDP by 2035 compared to the current value by more than two times [1]. It should also be noted that our state, as a member of the European Energy Community, implemented the European Union Directive 2009/28/EC on the promotion of renewable energy and provided for the introduction of a mandatory share of renewable energy in the structure of the country's total consumption at the level of 11 % in 2020 [2].

In order to achieve the goals set by the state energy policy, it is necessary to maximally reduce the energy consumption of all objects and equipment, including and those used in the oil and gas industry of Ukraine. This fully applies both to the oil and gas technological transport as a whole, and also to such an important component of it as lifting installations for the repair of wells. The specified installations have diesel power drives with mechanical transmissions that are less economical compared to the electric drive, which requires, among other things, the search for new directions for improving the fuel-economical characteristics of the power drives of lifting installations [3].

Costs for the operation of technological transport make up a significant share of the cost of products in the oil and gas industry, therefore reducing energy consumption and the cost of technological work during the operation of power drives of lifting units for repairing wells is an urgent task for specialists in the oil and gas industry [4]. The main directions for reducing the energy consumption of lifting installations for the repair of wells, which are investigated in this work, are:

- effective use of excess heat of the work process;
- provision of quick warm-up and maintenance of the optimal temperature regime of the transmission.

For performing complex works on capital repair of deep wells, high-capacity lifting units and derricks are used, which allows you to perform lowering and lifting operations with drill and casing pipes. The complex of such equipment turns into a mobile drilling rig. Thus, on the basis of a small number of unified nodes, constructions of lifting installations of various purposes and parameters are built [5].

Mobile installations for the repair of drilling wells functionally represent a system of one (most often) or two drive motors and a transmission – a converter that transfers and transforms the energy of rotation of the motor shaft into the energy of a hook that moves forward. The minimum necessary multiplicity of adjustment of the frequency of rotation and moments on the winch shaft of the elevators for their execution of lowering and lifting and technological operations is within the range of approximately 1:4. From the external characteristics of the internal combustion engine, it follows that the torque changes in a shorter interval. In this connection, there is a need to use mechanical, hydrodynamic or combined converters in the transmission [6].

Studies by a number of authors [7, 8, etc.] showed that the temperature regime of mechanical transmissions in conditions of negative temperatures does not reach the optimal values of the operating temperature of transmission units even after three hours of operation at different loading modes.

According to studies [9, 10, etc.], power losses in the transmission directly depend on its operating temperature, because the viscosity of the transmission oil increases with a decrease in the ambient temperature. Modern oils are characterized by different operational and viscosity-temperature properties. According to research results [9], the viscosity of mineral transmission oil 80W-90 changes significantly already at temperatures below +10 °C, at temperatures minus 25...30 °C it reaches solidification. According to the presented studies, it was concluded that when the ambient air temperature decreases during the winter period of operation, as a result of a decrease in the average temperature of the oil, its viscosity in aggregates is significantly higher than optimal values, which caused increased gear wear.

When studying the thermal modes of operation of car transmission units during operation in conditions of negative temperatures, it was established that the average temperature of the units' oil is significantly influenced by the vehicle's operating mode and the speed and direction of the air blowing the car. When the car is running at an ambient temperature of minus 20 °C with stops, the total duration of which is equal to the total driving time, the average temperature drop in the gearbox is 19 °C, and in the transfer box by 13 °C [10]. Based on this, it can be concluded that the mode of movement with stops is of significant importance when considering the thermal mode of the transmission during its operation in conditions of negative temperatures.

Study of suitability of cars GAZ-66, ZIL-131, etc. according to the thermal regime of the units, they showed that at an ambient air temperature of minus 40 °C, the temperature of the oil in the crankcase of gearboxes ranges from 2 to 33 °C [11].

The optimal thermal mode of operation of units of the mechanical transmission of lifting installations is not established by the manufacturer in a strict framework. The decisive factor is the performance of the oil under certain conditions. So, for example, the maximum temperature of TSP-15K transmission oil is established, which in the transmission units of UPA-60/80 lifting units of cars should not exceed 120 °C [12].

The minimum limit is set by the viscosity-temperature characteristic of the used oil (not lower than minus 30 °C). According to the authors [13], the optimal temperature of oil with a viscosity index of 80W-90 in the crankcase of the gearbox of the lifting unit URB-2A2 on the chassis of the Ural-4320 car, from the point of view of minimizing energy losses, is 30 °C.

PURPOSE AND TASKS OF RESEARCH

Costs for the operation of technological transport make up a significant share of the cost of products in the oil and gas industry, therefore, reducing energy consumption and the cost of technological work during the operation of power drives of lifting units for repairing wells is an urgent problem for specialists of the oil and gas industry.

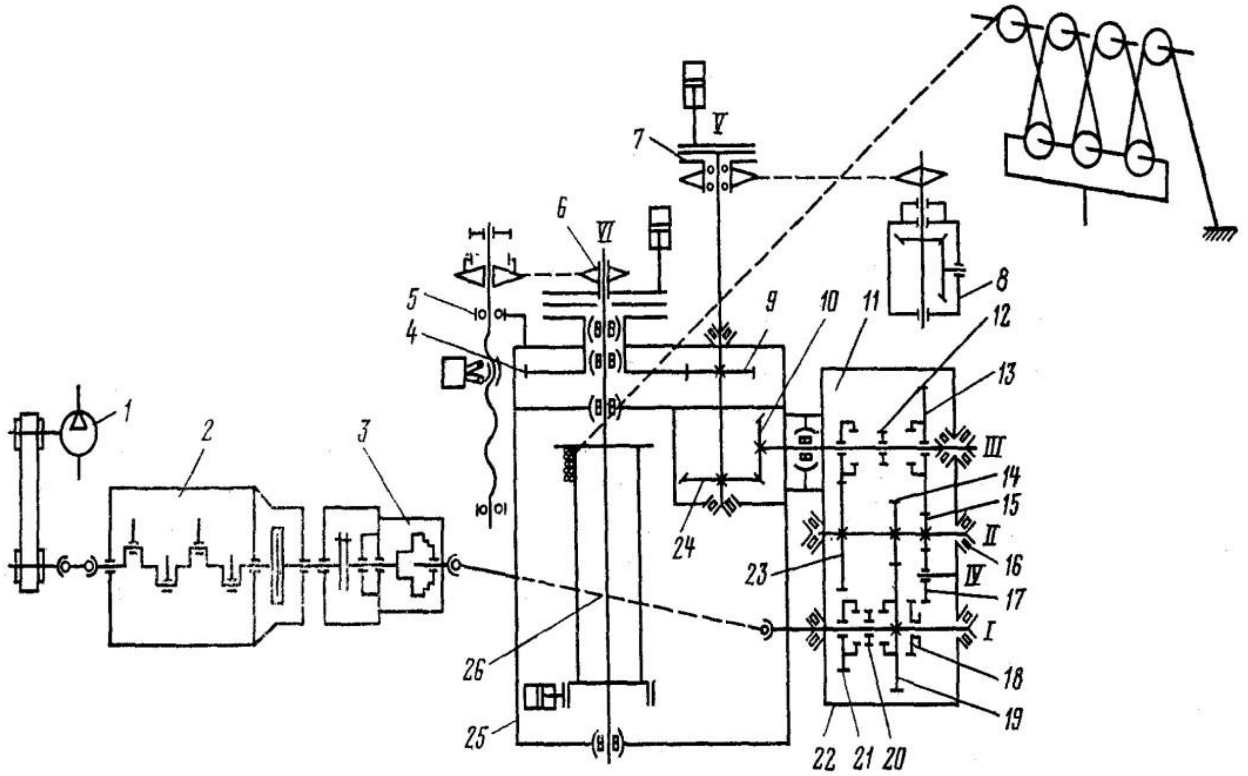
Therefore, the purpose of this article is to establish in laboratory conditions the main patterns of changes in the energy and power characteristics of transmissions of lifting units for the repair of wells in the oil and gas industry during the implementation of the proposed energy-efficient solutions. According to the goal, the research program includes the following tasks: experimental studies of energy consumption in transmissions of existing lifting units for well repair; experimental studies of energy consumption in transmissions of improved lifting units for repairing wells with the proposed highly efficient system of heating transmission units with spent gases.

PRESENTATION OF THE MAIN RESEARCH MATERIAL

A typical scheme of transmissions

Features of the construction of lifting installations are determined by the depth of the well, the content of operations, road and climatic conditions. The operating conditions of well repair equipment are complicated by low or high ambient temperatures, the condition or availability of the road network, etc. These conditions are the basis for the design and manufacture of the equipment, and especially strict requirements for the design of the equipment for the most mobile process - current repair of wells. The mobility of the well repair process and difficult road and climatic conditions in the main areas of oil and gas production in Ukraine, Europe and the world determine the main requirement for the equipment for this process – its high transportability.

Transportation of equipment in the summer period within the borders of Ukraine or Europe does not represent a difficult problem, because it can be provided by conventional wheeled transport bases. Transportation of equipment in conditions of snowy winter, spring or autumn off-road, was traditionally provided by high passability tracked transport bases. However, the experience of recent years has shown that the passability of such units, despite the tracked base, is not much different from the passability of wheeled units, and sometimes worse than them, because the crawler transporter-tractor maintains high passability only when it carries a small load. significantly less mass of the equipment aggregated on it. In addition, tracked conveyors destroy the road surface and have low speeds. Therefore, the optimal transport base for units for the repair of wells with a small carrying capacity is a standard car with high cross-country ability, for example, a KrAZ type car with three driving axles, tires with the ability to adjust the pressure and a sufficiently powerful engine. Cars of this class have sufficient cross-country ability, load capacity and speed of movement.



1 – compressor; 2 – engine; 3 – power take-off box; 4, 9 – gears of rotation of the drum shaft; 5 – tallow bloc; 6 – friction clutch; 7 – disc friction coupling; 8 – reversing gear; 10, 24 – bevel gears; 11 – the 3-rd and the 4-th speed gear; 12 – coupling; 13 – the1-st and the 2-nd speed gear; 14, 16, 23 – idle shaft gears; 15 – roller bearings; 17, 18 – gears of reverse rotation of the drum; 19 – the 2-nd and the 4-th speed gear; 20 – coupling; 11 – the 1-st and the 3-rd speed gears; 22 – gearbox housing; 25 – winch block; 26 – cardan shaft; I – drive shaft; II – idle shafts; Ш – driven shaft; VI – axis

Figure 1 – A typical mechanical transmission of a lifting rig for well repair AORS-60 on the KrAZ wheeled chassis

As transmissions and power converters for hoisting installations for the repair of wells produced in Ukraine, the former CIS and foreign production of small load capacity, mechanical gearboxes are mainly used, in most cases gear, less often chain with stepped regulation of the rotation frequency. A typical mechanical transmission of a lifting unit for repairing wells on a wheeled chassis (AORS-60) is shown in Fig. 1.

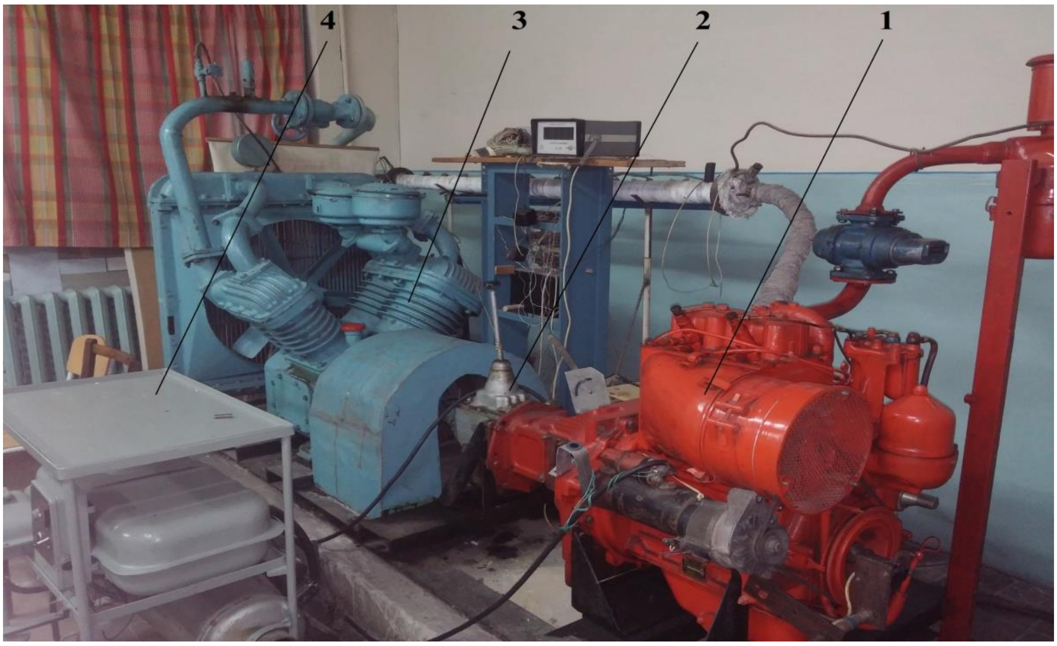
On a car or tractor transport base, the standard gearbox of the transport base itself is often used as a torque converter from the engine. The transmission of the well repair unit consists of a set of clutches, shafts, chain gears, a winch and a polyspast connected to the hook block. A hoist with a hook and blocks is called a hoist system, which is placed on the tower of the lifting device. The number of speeds and their ratio are determined depending on the technology of lowering and lifting operations. Such a scheme of the lifting installation, built on mechanical transmissions, is currently the most common in Ukraine.

Planning of experimental studies

The purpose and tasks of experimental studies of the characteristics of lifting installations for well repair determined the selection of the necessary equipment, measuring equipment and apparatus and objects for testing.

The task of experimental research is to determine the main patterns of energy consumption of standard transmissions of existing lifting installations and improved transmission with the proposed system of heating transmission units with exhaust gases of the engine. At the same time, it is expedient to determine, as a result of experimental research, the appropriate systems of parameters that determine energy consumption indicators. The solution to this problem is the implementation of a multifactorial experiment with the reproduction of the main conditions of the flow of the investigated processes.

Drawing up a plan of experimental studies in accordance with the provisions of the theory of experimental planning creates conditions for increasingg the reliability of measurement results



1 – converted engine to diesel D21A1; 2 – transmission; 3 – K-5M compressor; 4 – air heating device

Figure 2 – Appearance of the experimental stand based on the D21A1 diesel engine

and in many cases significantly reducing the volume of experimental studies and/or bench tests. But the successful application of modern methods of experimental research planning (for example, drawing up factorial plans) presupposes the mandatory availability of a certain minimum of information on the relationships between the studied factors.

The analysis of literary sources on this problem showed that there is still no reliable information on the energy consumption of transmissions of lifting units for the repair of wells in the oil and gas industry. It can only be asserted that the energy consumption indicators of the transmissions of lifting units for the repair of wells are affected by the temperature of the environment and transmission units. But the factorial plans guarantee obtaining, as a result of the minimum number of studies, reliable values of the coefficients in the regression equations only if the order of the regression equation is known before the beginning of the experiments. Moreover, conducting experimental studies using factorial designs is possible only with sufficiently specific theoretical ideas about the processes under study.

- Planning the research, the following tasks were set:
- create condition readings for evaluating random measurement errors;
- ensure minimum values for systematic errors and exclude gross errors;
- to ensure the adequacy of reproduction of experimental parameters from study to study;
- ensuring minimum deviations of parameters characterizing the conditions of experiments (humidity, pressure and temperature in experimental installations).

Methodology of experimental research

The experimental verification of the developed theoretical provisions was carried out in the conditions of the laboratory of heat engines of the Department of Motor Transport of the Ivano-Frankivsk National Technical University of Oil and Gas on the basis of the power drive of the D21A1 diesel engine (Fig. 2), which includes measuring equipment and a gearbox installed on a stand . Given that the mechanical transmission has physical, geometric and thermal similarities, the obtained research results can be extended to the gearboxes of cars and lifting installations.

The registration of the data necessary to determine the thermal regime of the gearbox under the influence of low temperature was carried out in the conditions of the same laboratory on an experimental installation based on an Electrolux mobile air conditioner.

A measuring complex based on a personal computer, an eight-channel motor tester and chromel-kopel thermocouples was used to record the temperature of exhaust gases and transmission oil. One of the sensors was installed at the outlet of the exhaust manifold (to the recuperator), the other - in the transmission units, immersed in oil. At the same time, the sensitive elements of the temperature sensors (chromel drops) were located in the center of the cross section of the exhaust gas discharge pipe. Readings of exhaust gas and transmission oil temperature sensors were recorded continuously. The exhaust gas temperature was recorded using chromel-drop thermocouples with a deviation limit of ± 2 °C in the range of measured temperatures from minus 20 to plus 380 °C. The temperature of the oil in the gearbox housing and the ambient air was measured using resistance thermotransducers with a permissible deviation of temperature values of ± 0.2 °C.

To study the temperature of the transmission oil, two temperature sensors were installed in the gearbox housing. Sensor No. 1 was installed in the lower layer of the gear section of the first gear and reverse gear, sensor No. 2 – in the upper layer of oil near the gears of the 5th gear.

The primary shaft of the gearbox was driven by the D21A1 diesel engine. The crankshaft of the diesel engine was rotated with the help of a direct current electric motor. For this purpose, the standard D21A1 diesel engine starter was replaced with a special direct current geared electric motor. The electric motor was powered by a 14 V and 500 A power supply unit.

Power losses in the gearbox were measured by measuring voltage and current on the drive electric motor. Power losses in the gearbox were calculated using the formula

$$N_{кп} = U_{en+gb} \cdot I_{en+gb} - U_{en} \cdot I_{en}, \text{ Wt,} \quad (1)$$

where U_{en+gb} – voltage drop on the drive electric motor when cranking a diesel engine with a gearbox connected through the clutch, V;

I_{en+gb} – the current consumed by the drive electric motor when cranking a diesel engine with a gearbox connected through the clutch, A;

U_{en} – voltage drop on the drive electric motor when cranking the diesel engine with disconnection through the clutch by the gearbox, V;

I_{en} – the current consumed by the drive electric motor when cranking the diesel engine with disconnection through the clutch by the gearbox, A.

The selection of the optimization parameter was carried out on the basis of research tasks, according to which it is necessary to obtain experimental data on the combined effect of a number of factors (gear rotation speed, gearbox operation time, ambient air temperature, technical condition of the transmission unit, oil viscosity, geometric dimensions, etc.) on the power loss of the gearbox.

The oil temperature in the transmission unit, the temperature of the ambient air, the temperature of the exhaust gases, the operating time of the units, the frequency of rotation of the primary shaft of the unit, which meet all the necessary requirements, were chosen as the main investigated parameters: quantitative assessment; unequivocal quantitative assessment; efficiency in the statistical sense, i.e. determination with high accuracy; availability of measurement and universality; unambiguity in all states of the object under study. The following factors were chosen as other factors: oil type, technical condition of the gearbox, etc., which were maintained at a constant level.

To experimentally confirm the possibility of implementing the proposed measures to reduce the oil heating time in the gearbox of the lifting unit during engine operation, the current values of the following parameters were recorded during the experiment: engine exhaust gas temperature; oil temperature in the gearbox crankcase; ambient temperature; engine operation time without and together with the heating system.

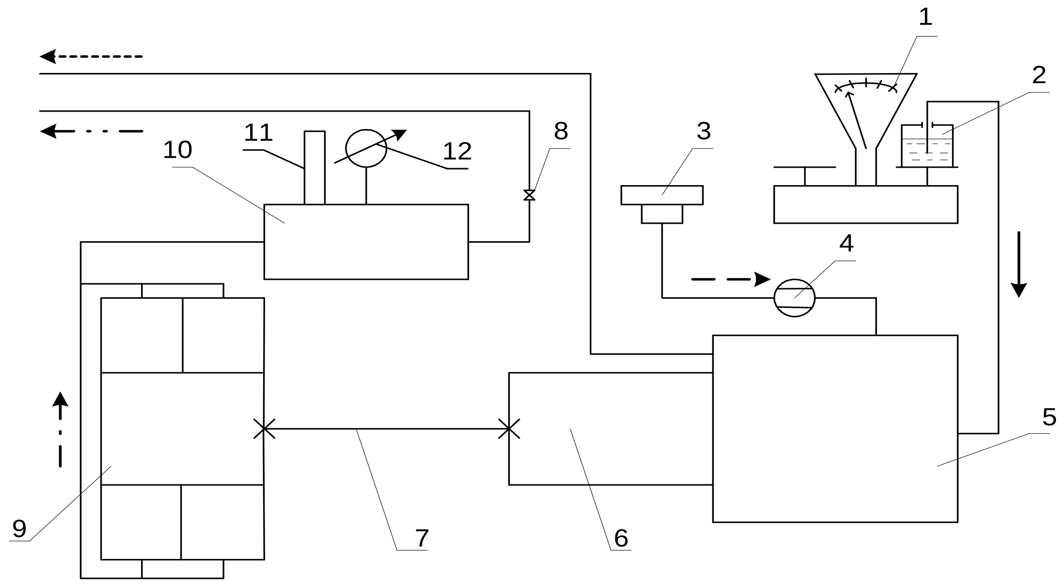
Means of experimental studies of the energy efficiency of transmissions of lifting installations

Stend tests were carried out on an experimental installation that included a serial D21A1 diesel engine and a serial gearbox from a ZIL-130 model 130-1700010-10 car. The scheme of the experimental installation based on the D21A1 diesel engine is shown in Fig. 2.

The load for the D21A1 experimental engine (Fig. 3, item 5) is created using a four-stage, four-cylinder air compressor of the K-5M model (Fig. 3, item 9). The power on the crankshaft of the K-5M compressor can be adjusted in the range of 1...30 kW, which allowed 100% loading of the experimental convertible engine and gearbox. The torque from the converted D21A1 engine to the compressor was transmitted using a cardan transmission (Fig. 3, item 7) and a model 130-1700010-10 gearbox (Fig. 3, item 6).

The mass of spent diesel fuel was determined using an electronic scale. A flow meter and a manometer were used to measure the volumetric flow rate and pressure of exhaust gases (Fig. 4). The main measuring devices and recording equipment are shown in Fig. 5.

ISSN 1993–9868 print
ISSN 2415–3109 online



– directions of fuel movement in the power supply system of the experimental installation;
– directions of air movement in the power supply system of the experimental installation;
– air movement from the compressor to the receiver;
– the movement of engine exhaust gases to the gearbox and into the environment;
– air movement from the receiver to the environment;

1 – fuel consumption measurement weight; 2 – capacity for alternative fuel; 3 – air cleaning filter; 4 – gas meter; 5 – experimental alcohol-gas engine; 6 – gearbox; 7 – cardan transmission; 8 – throttle pipe; 9 – load (compressor); 10 – the receiver; 11 – thermometer measuring the temperature of the environment; 12 – gas pressure gauge

Figure 3 – Scheme of the experimental installation based on the D21A1 diesel engine

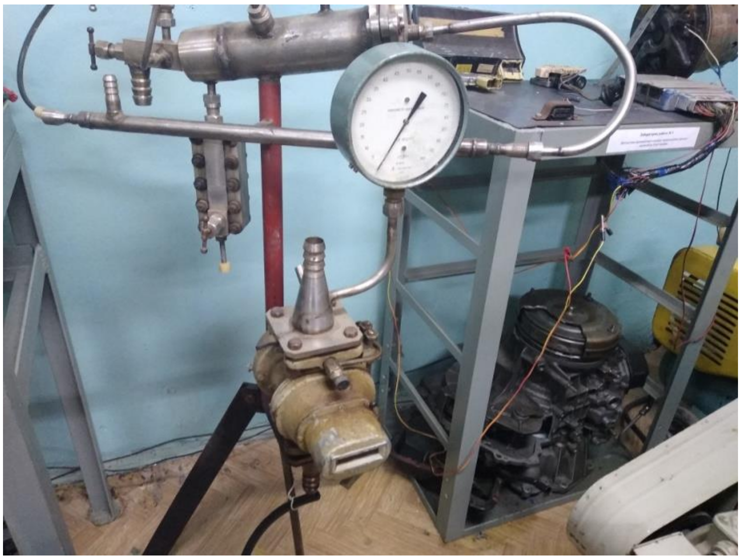
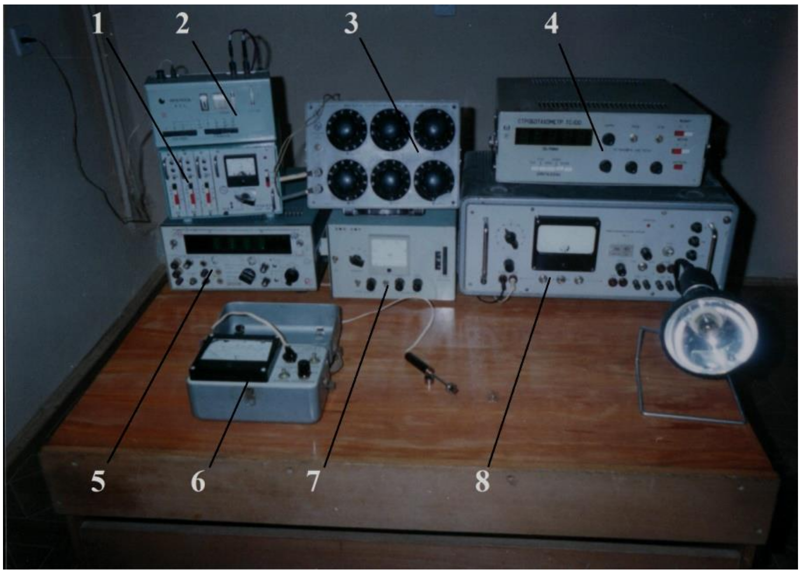


Figure 4 – A flow meter for measuring the volume flow of exhaust gases and a manometer for determining the gas pressure

Results of experimental studies of temperature changes of the proposed energy saving scheme in transmission units

The purpose of these experimental tests was to obtain functional dependencies of the influence of environmental factors and working time on oil temperature in a mechanical gearbox when working without or with a heat supply system.

Conducting experimental studies of the proposed energy saving scheme in transmission units due to heating by exhaust gases, the change in transmission oil temperature and energy losses in the transmission were determined. This stage of research is devoted to the determination of rational design parameters of elements of the heat supply system, the calculation of which is complicated for



1 – PT-4-01M amplifier; 2 – universal meter RCL-3; 3 – store of variable resistors MSSR-60M; 4 – electronic strobotachometer TSt-100; 5 – digital voltmeter B7-20; 6 – ETP-M ammeter; 7 – ETP-M ammeter; 8 – universal power supply unit UIP-2

Figure 5 – Measuring devices and recording equipment

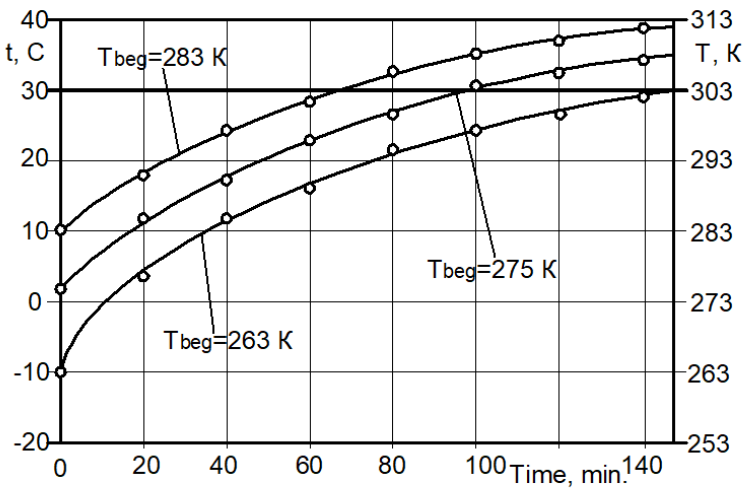


Figure 6 – Experimental dependence of temperature change mineral transmission oil in the gearbox

a number of reasons, as well as the clarification and verification of calculation parameters for the development of recommendations for increasing the efficiency of the heating system of transmission units. For the efficient operation of the heat supply system in the first minutes of engine operation, it is necessary to ensure the maximum transfer of heat from the exhaust gases to the transmission units. In order to fulfill the specified task, studies of heat transfer from exhaust gases to transmission oil were carried out.

Determining the thermal mode of operation of the mechanical gearbox, it was established that the ambient air temperature significantly affects both the intensity of the change in the temperature of the transmission oil and the duration of the period when the transmission unit reaches a stable temperature mode. It was established (Fig. 6) that when the drive shaft of the gearbox is rotated at idle speed (800 min^{-1}) at an ambient temperature of 263 K (minus 10 °C), the temperature of the gearbox oil rises in 140 min. up to 302 K (29 °C). Rotating the drive shaft of the gearbox at idle speed for the same time from temperatures of 275 K (plus 2 °C) and 283 K (plus 10 °C), the temperature of the gearbox oil rises, respectively, to 308 K (35 °C) and 312 K (39 °C). The heating time for the optimal temperature regime of 30 °C of the transmission unit at an ambient temperature of 263 K (minus 10 °C) is 146 min.

ISSN 1993–9868 print
ISSN 2415–3109 online

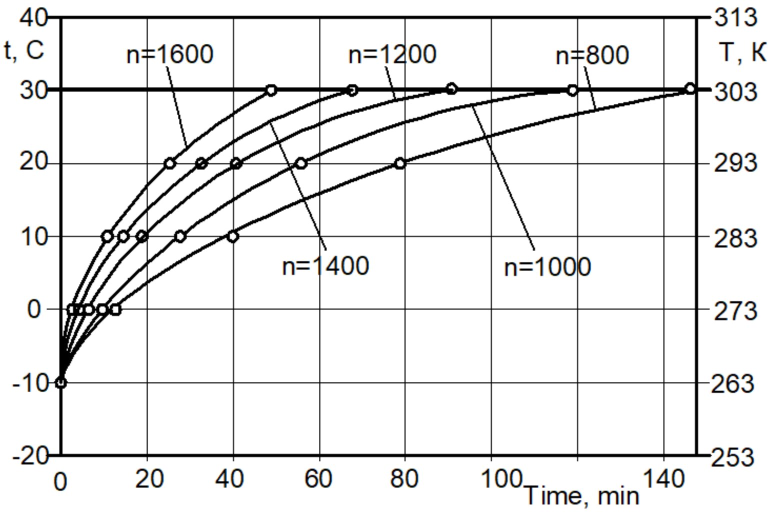


Figure 7 – Experimental dependences of changes in the temperature of the mineral transmission oil in the gearbox at different modes of rotation of the primary shaft of the gearbox

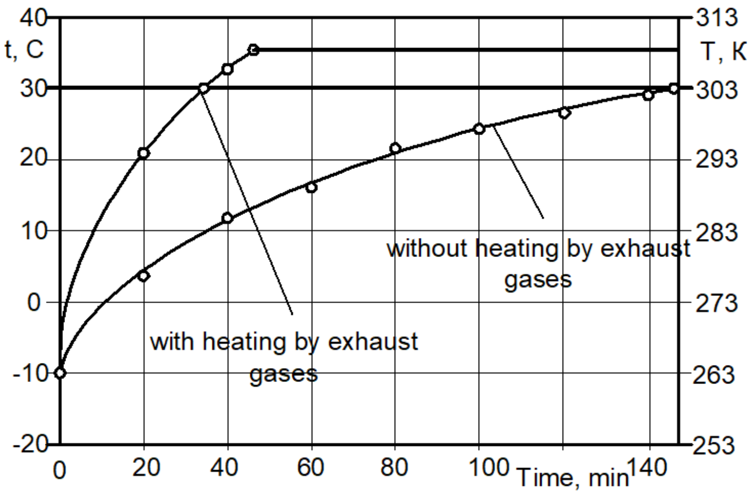


Figure 8 – Experimental dependencies of changes in the temperature of the mineral transmission oil in the gearbox during the modes of rotation of the primary shaft of the gearbox with/without heating by exhaust gases

Determination of the thermal regime of the mechanical gearbox at different speed modes was carried out by increasing the frequency of rotation of the primary shaft of the gearbox to 1000 min^{-1}, 1200 min^{-1}, 1400 min^{-1}, 1600 min^{-1}. The test results are shown in Fig. 7.

It can be seen from the graph that an increase in the frequency of rotation of the primary shaft of a mechanical gearbox leads to a significant increase in the temperature of its oil. At the same time, at speeds of rotation of the primary shaft of the gearbox 1000 min^{-1}, 1200 min^{-1}, 1400 min^{-1}, 1600 min^{-1}, the heating time to the optimal temperature regime of 30 °C of the transmission unit at an ambient temperature of 263 K (minus 10 °C) is, respectively, 118, 91, 68 and 48 minutes.

The results of experimental studies of the thermal state of the gearbox without heating by exhaust gases (standard mode of existing lifting plants) and with heating by spent gases (the proposed mode of improved lifting plants) are shown in Fig. 8. It follows from the obtained results that in the regular mode of the existing lifting units, the optimal temperature of 30 °C is reached after 146 minutes, and in the proposed mode of the improved lifting units, the optimal temperature of 30 °C is reached after 34 minutes, after 45 minutes the temperature of 35 ° is reached C, and the forced heating mode turns off.

During the research, it was established that the main factors affecting the thermal state of the mechanical gearbox at a given rotation frequency are the operating time, the temperature of the exhaust gases, and the temperature of the gearbox oil. In addition, it was established that the temperature of the oil in the gearbox in some cases during the operation of the power drive engine at idle speed does not reach the required optimal value of 313 K even after 3 hours of operation. Based on this, an exhaust gas heating system is used to increase the temperature of the oil in the mechanical gearbox.

In the process of processing the experimental dependences of the oil temperature in the mechanical gearbox on the temperature of the exhaust gases and the time of operation together with the heat supply system (Fig. 8), it was established that when the engine is operating with the minimum frequency of rotation of the crankshaft at idling speed (800 min^{-1}), the ambient temperature air significantly affects both the dynamics of the temperature of the transmission oil in the manual gearbox and the time it takes to heat the transmission oil to the optimal temperature of 303-313 K.

The analysis of the obtained data shows that the average heat flow transferred from the exhaust gases in 30 min. significantly changes when the crankshaft rotation frequency increases from 800 to 1600 min^{-1}. Especially in the first 20 minutes. work, a significant increase in heat transfer values is observed, and the second stage of work (20-45 min.) is characterized by a decrease in the transferred heat flow. This is due to the intensity of the increase in the temperature of the oil in the gearbox, while the average temperature difference of the coolants changes to a lesser extent with an increase in the crankshaft rotation frequency.

The analysis of the obtained data showed that a decrease in the ambient temperature leads to a decrease in the dynamics of the oil temperature, and it can be argued that this dependence has a non-linear nature. At the same time, as the gearbox warms up, the influence of the ambient air temperature becomes less significant. The obtained data also make it possible to determine the necessary time for heating the KP oil to the optimal temperature of 303-313 K when the ambient temperature changes from 253 to 283 K.

Comparative tests of the thermal state of the gearbox when working both with and without a heat supply system showed that the transferred heat affects both the rate of temperature change and the time it takes for the oil temperature to reach the optimal temperature of 303-313 K and the gearbox to reach a stable temperature mode.

The results of experimental studies on the reduction of energy losses of the proposed energy saving scheme in transmission units due to heating by exhaust gases

The study of power losses with a mechanical gearbox included the determination of total losses (hydraulic and mechanical) to overcome rotational resistance forces depending on the temperature of the transmission oil. Losses in the gearbox of the car are similar to the consumption of power consumed by the electric motor of the installation, taking into account the power of mechanical losses, which is lost in the drive motor itself. Two brands of the most commonly used transmission oils were used for research: mineral TAp-15B SAE 80W-90 API GL-3 and semi-synthetic TM-5-18 SAE 75W90 API GL-5. The first oil is used in the oil and gas industry of Ukraine for transmissions of lifting installations manufactured in the former CIS countries, the second oil – for transmissions of lifting installations manufactured in the USA, Canada, and European countries.

As a result of the study, it was established that the power required to rotate the gearbox at an ambient temperature of 263 K at the time of starting the engine was 902 W for TAp-15B mineral oil, 625 W for semi-synthetic TM-5-18 (Fig. 9). Further scrolling of the gearbox at 273 K led to a decrease in power consumption, reaching 720 W for TAp-15V oil and 540 W for TM-5-18. At an oil temperature of 303 K, power losses when using oils of different grades were practically equal and amounted to 448 and 425 W for mineral and semi-synthetic oil, respectively.

To check the adequacy of the obtained analytical model in Fig. 9, theoretical dependences of changes in power loss in the gearbox on the temperature of the transmission oil were placed. The combination of theoretical and experimental dependences showed that the maximum discrepancy regarding the range of changes in power loss from temperature does not exceed 6 %. This testifies to the satisfactory adequacy of the obtained mathematical model.

On the basis of the developed and confirmed mathematical model for the UPA 60/80A well repair hoist on the KrAZ-63221-04 chassis (Fig. 10), calculations were made for power losses in the gearbox. The AORS-60 lifting unit on the KrAZ-63221-04 chassis can be equipped with a 176 kW (240 hp) engine or a 220 kW (300 hp) engine.

As a result of the study, it was established (Fig. 11) that the power required to rotate the gearbox at an ambient temperature of 253 K at the moment of starting the engine for TAp-15V mineral oil is 14.20 kW, for semi-synthetic TM-5-18 – 9.50 kW. Further scrolling of the gearbox at 273 K leads to a decrease in power consumption, reaching 9.30 kW for TAp-15V oil and 6.95 kW for TM-5-18. At an oil temperature of 313 K, power losses when using oils of different grades are practically equal and amount to 4.85 and 4.80 kW for mineral and semi-synthetic oil, respectively.

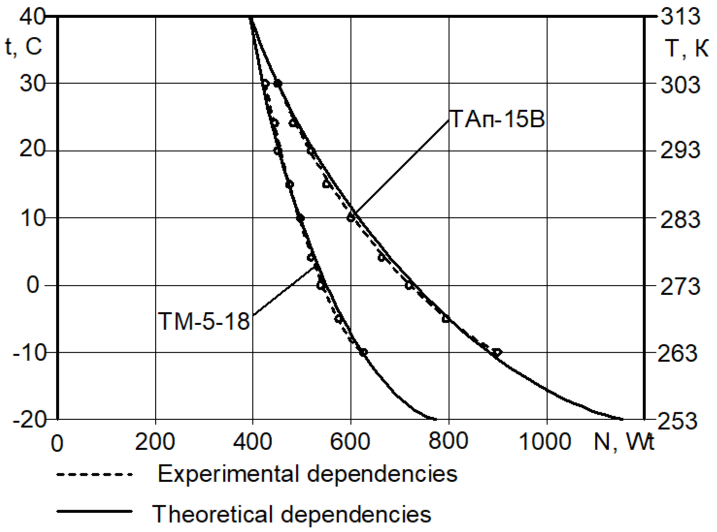


Figure 9 – Dependence of power losses in the gearbox depending on the temperature and type of transmission oil

Figure 10 – AORS-60 model well-repair lifting unit

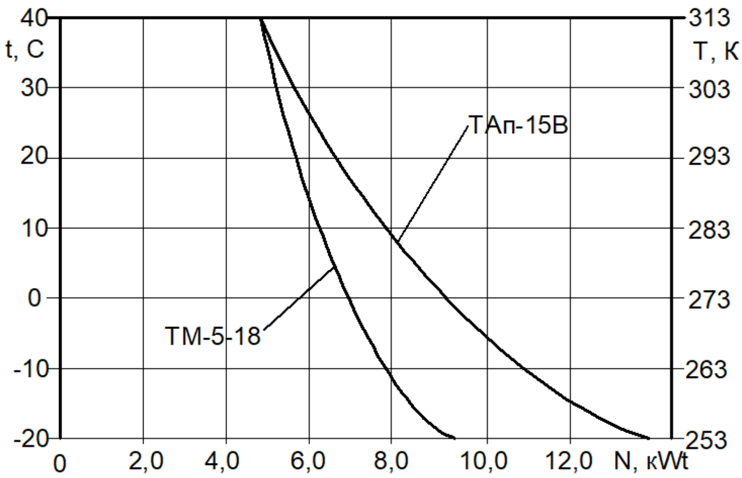


Figure 11 – Theoretical dependence of power losses in the gearbox of the AORS-60 lifting unit depending on the temperature and type of transmission oil

Table 1 – Results of fuel consumption calculations in the gearbox of the AORS-60 model hoist with different power drives and at different transmission oil temperatures

Temperature, K	Power consumption in the gearbox, kW		Engine / values of the minimum effective specific fuel consumption, g/(kWh)		Fuel consumption for gearbox drive, semi-synthetic oil, kg/h.	Fuel consumption for gearbox drive, mineral oil, g/h.
	Semi-synthetic oil	Mineral oil	YaMZ-238BE2	YaMZ-238VM		
313	4,80	4,85	195	214	0,93-1,02	0,94-1,04
273	6,95	9,30			1,36-1,49	1,81-1,99
253	9,50	14,20			1,85-2,03	2,77-3,03

We will calculate the excess fuel consumption in the gearbox of the AORS-60 lifting unit with different power drives and at different transmission oil temperatures (Table 1).

The average specific fuel consumption of 220 g/(kW h) can be assumed for the main technological modes associated with drilling and repair of wells. The values of the minimum effective specific fuel consumption of atmospheric YaMZ-238VM engines with a capacity of 176 kW at engine crankshaft revolutions of 1300 min^{-1} were 214 g/(kW h); nominal effective specific fuel consumption of atmospheric YaMZ-238VM engines at engine crankshaft revolutions of 2100 min^{-1} – 259 g/(kW h). The values of the minimum effective specific fuel consumption of YAMZ-238BE2 supercharged engines with a capacity of 220 kW at engine crankshaft revolutions of 1400 min^{-1} were equal to 195 g/(kW h); nominal effective specific fuel consumption of YAMZ-238BE2 supercharged engines at engine crankshaft revolutions of 2100 min^{-1} – 238 g/(kW h).

DISCUSSION OF RESEARCH RESULTS AND CONCLUSIONS

The conducted studies showed that reducing energy consumption in the transmissions of lifting units for repairing wells by using the heat of exhaust gases to ensure rapid heating of transmission units and maintaining the optimal thermal regime is quite profitable.

As a result of the calculations, it was established that the excess fuel consumption required to rotate the gearbox of the AORS-60 model lifting unit with various power drives at an ambient temperature of 253 K at the time of start-up for TAp-15B mineral oil is 1.83-1.99 kg , for semi-synthetic TM-5-18 – 0.92-1.01 kg compared to a temperature of 313 K. Further scrolling of the gearbox at 273 K leads to a decrease in fuel consumption, reaching 0.87-0.95 kg for TAp oil 15V and 0.43-0.47 kg for TM-5-18 compared to a temperature of 313 K.

Therefore, the analysis of the obtained experimental data showed that high efficiency of heat transfer to the transmission units and reduction of energy consumption in the transmission can be achieved due to temperature differences of exhaust gases and transmission oil. A significant incentive for the further development of such systems is that they determine the possibility of overall improvement of the characteristics of the vehicle according to a set of indicators. Their implementation on vehicles makes it possible to utilize waste thermal energy and reduce fuel consumption by oil and gas technological transport.

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