Experimental studies of the effect of adding the antifriction additive Multi-Tech-Conditioner to lubricating oil on the power of mechanical losses of a rotary piston engine were carried out, the purpose of which was to reduce the cost of potential energy of a compressed working fluid to overcome friction forces. The experimental data obtained make it possible to estimate the value of irretrievable losses of the available power of a rotary piston engine at the stage of its design and operation.

Experimentally, a positive effect of the addition of the Multi-Tech-Conditioner antifriction additive to lubricating oil on the change in the power of mechanical losses of the engine was established, which was reflected in a decrease in total losses over the entire operational range of change in the rotor speed by 11.8 %. As a result of the research, it was determined that the losses for pumping strokes (gas exchange) in a rotary piston engine amount to 31.6 % of the total power of mechanical losses.

An assessment was made of change in the mechanical efficiency of a rotary piston engine with a hinged-cam mechanism for converting motion under the conditions of applying an antifriction additive to lubricating oil. It has been established that the addition of the Multi-Tech-Conditioner additive to the lubricating oil in a ratio of 1:14 makes it possible to increase the mechanical efficiency of a rotary piston engine depending on the speed by 3.8–5.5 % for all operating pressures in the inlet receiver.

Based on the generalization and systematization of the obtained experimental data on the use of the Multi-Tech-Conditioner additive, the most rational operating ranges of a new design rotary piston engine were identified. The maximum mechanical efficiency of a rotary piston engine is achieved in the load range of 65...75 % of the rated power, and the speed range is 63...70 %

Keywords: rotary piston engine, mechanical losses, anti-friction additive, pumping stroke

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DETERMINING THE EFFECT OF ANTI-FRICTION ADDITIVE ON THE POWER OF MECHANICAL LOSSES IN A ROTARY PISTON ENGINE

Oleksandr Mytrofanov
Doctor of Technical Sciences, Associate Professor*
Arkadii Proskurin
Corresponding author
PhD, Associate Professor*
E-mail: arkadii.proskurin@nuos.edu.ua
Andrii Poznanskyi
PhD, Associate Professor
Department of Mechanical Engineering and Manufacturing Engineering**
Oleksii Zivenko
PhD, Associate Professor
Department of Marine Instrumentation**
*Department of Internal Combustion Engines, Plants and Technical Exploitation**
**Admiral Makarov National University of Shipbuilding
Heroiv Ukrainy ave., 9, Mykolaiv, Ukraine, 54007

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1. Introduction

A rotary piston engine with a cam-articulated mechanism for converting the translational movement of the piston into the rotational movement of the rotor is one of the promising types of pneumatic motors [1]. Due to its unique compact design, the engine can be successfully used in various critical infrastructure facilities, as well as in places where the use of electrical energy is difficult or impossible. The efficiency of a rotary piston engine, like any other mechanism, depends on the power of mechanical losses, an increase in which will lead to an increase in consumption and a decrease in engine reliability.

According to various estimates, the share of power of mechanical losses under the rated mode of operation of reciprocating engines in relation to the indicator averages 15...25 % [2]. That is, in fact, up to a quarter of the available energy is irretrievably lost, mainly to overcome friction forces and pumping losses. The level of mechanical loss power is directly affected by the imperfection of the design, manufacturing technology, as well as the materials used, and the antifriction, antiwear properties of the lubricating oils used.

The main purpose of lubricating oil is the formation of an oil film on the surface of the part to ensure a minimum coefficient of friction and wear of the rubbing surfaces of mating parts. In addition, the oil in the engine must provide sealing of gaps, removal of wear products, removal of friction heat, protection of surfaces of parts from corrosion and prevention of various kinds of deposits on surfaces. At the same time, the oil must retain its properties throughout the entire period of its use and under different engine operating conditions, and also have a maximum service life.

An effective way to increase the service life of engines, reduce the level of mechanical losses, and also ensure the desired properties of oils throughout the entire range of operation is the modification of lubricating oil by adding various additives [3]. There are a number of additives for various purposes. So, additives can be distinguished, the main purpose of which is to reduce wear, the required viscosity, as well as antioxidant, detergent, antifoam, friction modifiers, etc. [4]. However, the use of additives has both positive and negative consequences. For example, the use of friction modifiers, which are suspensions of graphite, molybdenum disulfide, and Teflon, significantly impairs the cleaning properties of the oil and its filterability. Sufficiently long-term use of them leads to excessive deposits on surfaces, clogging of filters, oil channels, and gaps, as well as deterioration in the thermal conductivity of parts. Accordingly, when selecting the necessary lubricating oil additive to ensure its greatest efficiency, it is necessary to take into account the design and operational features of the engine. Thus, the task of selecting the necessary additive is part of a set of measures to reduce the power of mechanical losses in engines and a relevant area of scientific research.

2. Literature review and problem statement

Increasing the efficiency of rotary piston engines is closely related to the improvement of lubricating oil, namely, changes in composition and performance properties. These changes are necessary to achieve the specified engine power and consumption, as well as to increase service intervals. The use of additives is an effective way to achieve these goals.

Paper [5] reports the results of a study into the effectiveness of an additive mixture consisting of ionic liquids, glycerol monooleate, molybdenum dithiocarbamate, and titanium dioxide nanoparticles in a biobased trimethylol propane trioleate (TMPTO) base oil. The performance of the additive blend and TMPTO was compared directly to standard SAE 0W-30 engine lubricating oil in a single cylinder diesel engine. It was found that the use of a mixture of additives with TMPTO increased maximum torque by 2.5 % and braking power by 3 %. However, it reduced the specific fuel consumption by 10 % throughout all the tests from 800 to 2300 rpm. It was also found that a mixture of additives with TMPTO made it possible to reduce the friction power by 20–25 % at 900, 1200, and 1500 rpm. Despite the clear advantages, the use of this bio-based lubricating oil in a rotary piston engine is difficult due to the lack of knowledge of other properties not related to tribology, for example, deposit control, low temperature properties, etc.

In [6], a polymer-based composite nanoadditive (PCNA) was studied, suitable for lubricating oil in diesel engines of military equipment. The results of experimental studies showed that the additive in the amount of 3 % vol. can improve the low-temperature fluidity and kinematic viscosity of the lubricating oil without affecting the temperature characteristics of the viscosity. It has also been found that the additive can effectively improve the anti-friction, lubricity, and anti-wear performance of lubricating oil. In addition, the addition of an additive helps improve the working condition of the engine, and also reduces noise. However, there are no data on the effect of the additive on mechanical losses and specific performance indicators of the engine.

In [7], the use of liquid boron as an additive to motor lubricating oil together with vegetable oil was studied. Experimental studies were first carried out using mineral lubricating oil in one engine. The experiments were then repeated using a mineral base oil with additives in a second engine with the same specifications as in the first. The study was carried out in the area of diesel engine performance (torque, power, fuel consumption) and exhaust gas emissions (CO, CO_2, HC, O_2, SO_2, NO_x). As a result, it was found that the engine, which used boron and mineral oil with vegetable oil, provided better fuel economy than the engine with mineral oil without additives. Also, the studied engines showed similarities in terms of exhaust emissions. However, there is no information in the work on the influence of the operating parameters of the engine operation on the change in mechanical efficiency under the condition of an additive.

In [8], lubricating oil SAE 5W-30 reinforced with dispersed graphene nanoplates is considered from the point of view of tribological and rheological properties. The influence of the concentration of graphene nanoplates on the thermal and tribological properties of the base oil was tested. The kinematic viscosity was calculated, the base oil and lubricant with the addition of nano-additives to 5W30 were compared in terms of thermal conductivity and flash point. The coefficient of friction decreased by 33 % when using nanoadditives. Compared to the base oil, flash point, thermal conductivity, kinematic viscosity and pour point increased by 25.4 %, 77.4 %, 29.9 % and 35.4 %, respectively. However, there are no experimental studies of the use of nanoadditives in real conditions on engines.

Papers [9, 10] report the results of testing a 4Ch17.5/24 (NVD 24) marine diesel engine with a power of 64 kW at 750 rpm. The tests were carried out on the engine when working with standard M10G2 oil (SAE 30), as well as with the addition of the Multi-Tech-Conditioner antifriction additive to the oil. «Multi-Tech-Conditioner» is a highly technical additive, commercially produced and available in the open market. According to the company I.E.U, the additive does not form emulsions that clog filters or can be deposited on the moving parts of the crankshaft and CPG. It was found that after the use of the additive, it contributed to a decrease in the power of mechanical losses by 9...11 %, as well as a decrease in hourly fuel consumption by up to 6 % at 75 % load. The pressure at the end of the compression process increased by an average of 0.12...0.15 MPa for the cylinders. At a constant engine load (constant effective shaft power), the indicated power decreases, and with it the hourly fuel consumption, while the mechanical efficiency increases by up to 2.6 %. However, in these works there is no information on the possibility of using this additive in engines and mechanisms of other designs.

Conducting experimental studies of the power of mechanical losses of a rotary piston engine under the conditions of using the additive «Multi-Tech-Conditioner» in comparison with works [9, 10] is necessary and relevant due to a number of factors. First of all, a rotary piston engine is a displacement expansion machine, and not an internal combustion engine (the expansion of the working fluid is associated with a decrease in temperature, to negative ones). In addition, the rotary piston engine has a number of significant design differences, primarily related to the mechanism for converting the translational movement of the piston into the rotational movement of the rotor. So, for example, in contrast to the design of a classic crank mechanism, the engine does not have such friction units as plain bearings, and the movement is converted by running the moving links along a special-shaped cam. Accordingly, the reduction of mechanical losses as a result of the use of the Multi-Tech-Conditioner additive on an internal combustion engine [9, 10] and a rotary piston engine can be different.

Taking into account the structural features of a rotary piston engine, the availability and research of additives used in engine building, our paper discusses the effectiveness of using the industrial anti-friction additive «Multi-Tech-Conditioner» to base oil. The obtained research results could become the basis for the development of practical recommendations regarding the design of new expansion machines of this type.

3. The aim and objectives of the study

The purpose of this experimental study is to determine the effect of an antifriction additive to oil on the power of mechanical losses of a rotary piston engine with a cam-articulated motion conversion mechanism. The studies will make it possible to evaluate the effectiveness of the use of the additive in the process of energy conversion of the compressed working fluid.

To achieve the goal, two main tasks can be distinguished:

– to establish the speed characteristic of the change in the power of mechanical losses and friction losses of a rotary piston engine when working with an antifriction additive;

– to determine the effect of an antifriction additive to lubricating oil on the change in the mechanical efficiency of the engine.

4. The study materials and methods

The object of our experimental research is mechanical losses in a rotary piston engine under conditions of application of an antifriction additive to lubricating oil.

The subject of the study is the characteristics of the change in mechanical losses depending on the operational parameters in the process of energy conversion of the compressed working fluid.

Experimental studies of the power of mechanical losses of a rotary piston engine with a cam-articulated motion conversion mechanism were carried out in two stages. At the first stage of experimental studies, the power of mechanical losses and the mechanical efficiency of the engine were determined depending on the operating parameters when using standard lubrication. Highly purified paraffin-based mineral oil TEXACO COMPRESSOR OIL EP VDL 46 was used as a lubricating oil in the pneumatic motor. The main averaged characteristics of the oil are given in Table 1.

Table 1

Main characteristics of mineral oil

No. of entry	Parameter	Value
1	Viscosity class according to ISO	46
2	Viscosity, cSt, at +40 °C	46
3	Viscosity, cSt, at +100 °C	6.8
4	Maximum pour point, °C	–30
5	Minimum flash point, °C	+209

The engine speed was controlled using a digital tachometer GM 8905-EN-00, the error of which is 0.1 %. For a more accurate registration of the speed, a Ch4-34A digital frequency meter was used. The absolute error for the rotation frequency range 10...30 s^{-1} is ± 1 s^{-1}. The voltage and current in the circuit were monitored using a PROTESTER M266C digital multimeter (measurement range 200 mV–1000 V, 20–1000 A; error, respectively, ±0.5 %, ±2.0 %). Temperature control was performed using a digital device OVEN UKT38-SCH4.TP using chromel-copel L (TKhK) and copper-constantan T (TMC) thermocouples. The accuracy class of the device OVEN UKT38-SCH4.TP is 0.25. A detailed description of the experimental bench (photograph in Fig. 1), as well as the conditions for the experiment and the results obtained, are reported in [11].

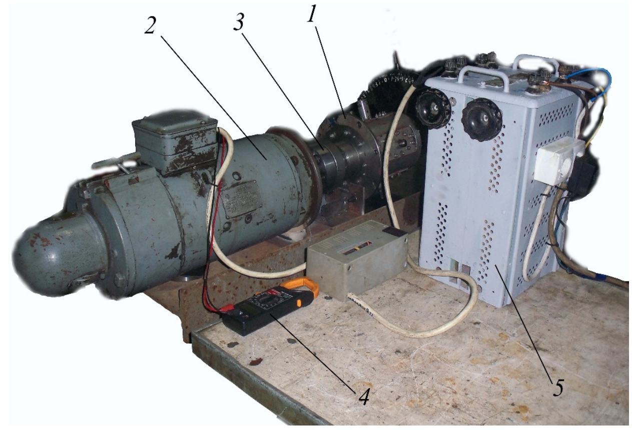


Fig. 1. Experimental bench for determining the power of mechanical losses of a prototype rotary piston engine 12 RPD 4.4/1.75 with a cam-articulated movement mechanism: 1 – rotary piston engine 12 RPD 4.4/1.75; 2 – DC electric motor 2PB-132MG; 3 – sleeve-finger coupling; 4 – digital multimeter PROTESTER M266C; 5 – autotransformer AOSN-20-220-75 UHL4

At the second stage of experimental studies, the Multi-Tech-Conditioner additive was used as an additive to the lubricating oil. This additive improves surface quality and reduces friction between surfaces. Anti-friction additive Multi-Tech-Conditioner in its composition does not contain combustible and harmful components, as well as suspended particles of solid substances, such as, for example, Teflon, graphite, and ceramics. Multi-Tech-Conditioner does not contribute to the formation of deposits in the filter or deposits on moving parts. The main characteristics of the Multi-Tech-Conditioner additive are given in Table 2 [12].

Table 2

Main characteristics of the antifriction additive Multi-Tech-Conditioner

No. of entry	Parameter	Value
1	Form	Liquid
2	Color	Light
3	Solubility in water	Insoluble
4	Density at 15 °C (according to DIN 51757), g/cm^3	1.06
5	Viscosity at 40 °C (according to DIN 51562), mm^2/s	17.9
6	Burning point (according to DIN ISO 2592), °C	122
7	Ignition temperature, °C	220
8	Pourpoint (according to DIN ISO 3016), °C	–42

According to the recommendation of the Multi-Tech-Conditioner manufacturer, as well as taking into account experimental works [9, 10], an additive was added to the lubricating oil of a rotary piston engine in a ratio of 1:14 (primary processing of motors). At the same time, before filling the oil cavity, the engine was thoroughly washed and dried. When conducting experimental studies, to ensure the required viscosity of the oil with the Multi-Tech-Conditioner additive, the engine was brought to normal thermal conditions, after which all measurements were performed.

The design of the engine [13] makes it possible to estimate the friction losses of the motion mechanism separately from the losses due to pumping strokes (without gas exchange). This is done by driving the cam-articulated mechanism by rotating the central control cam.

In order to eliminate random errors and improve the accuracy of the measurement results, two measurements were performed in each mode. At the end of the control measurement, the engine is transferred to the next mode of operation. If the results of the second measurement were significantly different from the first, a third measurement was taken. A series of measurements were carried out starting from the minimum engine speed and rising to the maximum, and then from the maximum to the minimum. During processing, the power of mechanical losses was calculated according to the known formula for determining the power of a DC electric motor:

$$N = IU\eta_e, \text{ W},$$

where I is the current strength, A; U – voltage, V; η_e – efficiency of the electric motor (passport value $\eta_e = 0.82$).

Approximation of the obtained experimental points was performed using the exponential function $y = e^x$.

5. Results of experimental studies of changes in the power of mechanical losses under conditions of application of an antifriction additive

5. 1. Determination of the speed characteristic of the change in the power of mechanical losses and friction losses when using an antifriction additive

Experimental studies of a prototype rotary piston engine were carried out without controlling the degree of filling, which corresponds to the average position of the cam. The engine speed varied in the range of 400...1500 min^{-1}. The power of mechanical losses of a rotary piston engine under the conditions of using standard lubrication varied within 262...865 W (Fig. 2). The addition of the anti-friction additive Multi-Tech-Conditioner made it possible to reduce the power of mechanical losses of the engine to values of 231...762 W (Fig. 2). Thus, the positive effect of the use of the additive is on average 11.8 %.

It should be noted that a significant increase in the power of mechanical losses with an increase in engine speed is primarily due to an increase in the resistance of the intake and exhaust tracts. The design of a rotary piston engine makes it possible to separately estimate the magnitude of friction losses in the cam-articulated mechanism for converting motion, excluding losses from mechanical losses due to pumping strokes from the power of mechanical losses. This is realized by scrolling the cam for adjusting the degree of filling of the cylinder. In this case, the engine rotor remains stationary (there is no gas exchange), and the cam-articulated mechanism sets the engine pistons in motion. So, Fig. 3 shows the results of experimental studies of friction losses in the motion conversion mechanism with and without additives.

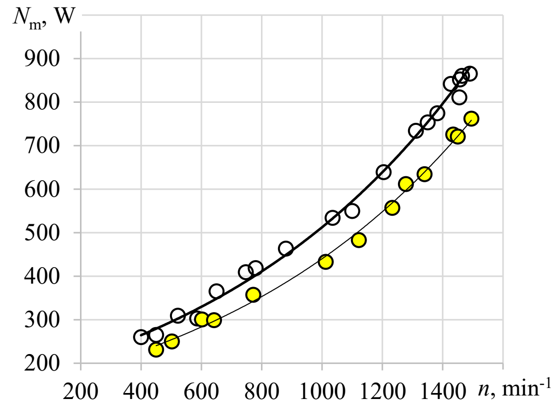


Fig. 2. Speed characteristic of change in the power of mechanical losses N_m of a rotary piston engine when operating on a standard lubricating oil and with additives of the Multi-Tech-Conditioner antifriction additive (filled dots correspond to the condition of using the additive)

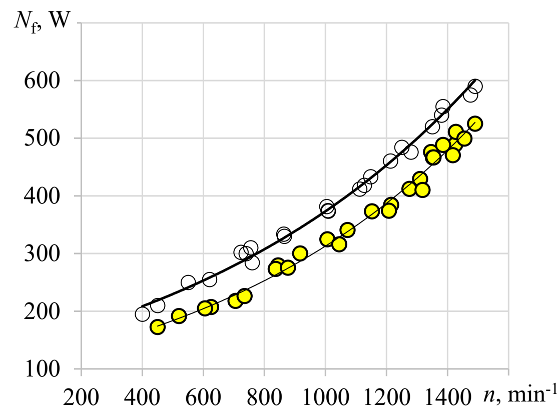


Fig. 3. Velocity characteristic of friction loss change N_f in a cam-jointed movement conversion mechanism when operating on standard lubricating oil and with additives of the Multi-Tech-Conditioner antifriction additive (filled dots correspond to the condition for using the additive)

The value of losses to overcome friction under the conditions of using a standard lubricant varied within 195...595 W, and in the case of the addition of an antifriction additive Multi-Tech-Conditioner – 172...526 W.

The value of losses for the performance of pumping strokes, depending on the speed, is approximately 25.6...31.6 % of the total power of mechanical losses of a rotary piston engine. Thus, the share of the power of the mechanical losses of the engine, associated with overcoming the forces of friction, is dominant.

5. 2. Investigation of the effect of an antifriction additive on the change in mechanical efficiency during engine operation according to the speed characteristic

Using the power of mechanical losses as a criterion for comparing and evaluating the irretrievable losses of different sizes of rotary piston engines is difficult. The generally accepted and most convenient parameter in engine building is mechanical efficiency. This parameter makes it possible to evaluate motors of different designs since it is the ratio of effective power N_e and indicated power N_i.

Fig. 4 shows the effect of the main operating parameters (engine speed and air pressure in the intake receiver) on the change in the mechanical efficiency of a rotary piston engine with and without the Multi-Tech-Conditioner antifriction additive. At the same time, the range of operating pressures of compressed air in the intake receiver of the engine was 0.4...0.8 MPa.

Systematized results of experimental studies into a prototype of a rotary piston engine with additives of the antifriction additive Multi-Tech-Conditioner to the lubricating oil and without it are given in Table 3.

The generally accepted approach to reduce mechanical losses of engines, in addition to design (for example, optimizing the geometric dimensions of gas distribution organs) and technological (improving the quality of parts manufacturing, using various materials and oil additives, etc.), is operational. This approach implies the choice of optimal operating modes in order to reduce mechanical energy losses in the engine.

Summarizing and systematizing the obtained data, it is possible to single out rational ranges of operation of a rotary piston engine in terms of achieving maximum mechanical efficiency (Fig. 5).

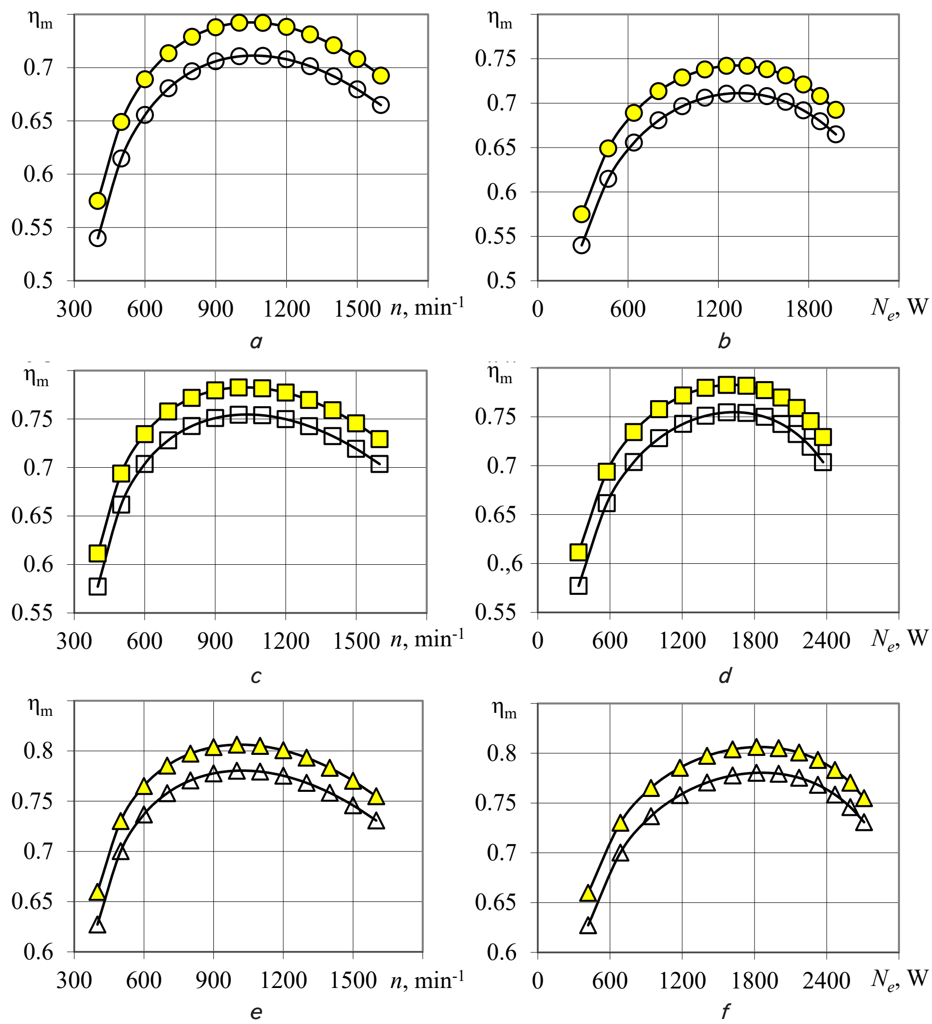
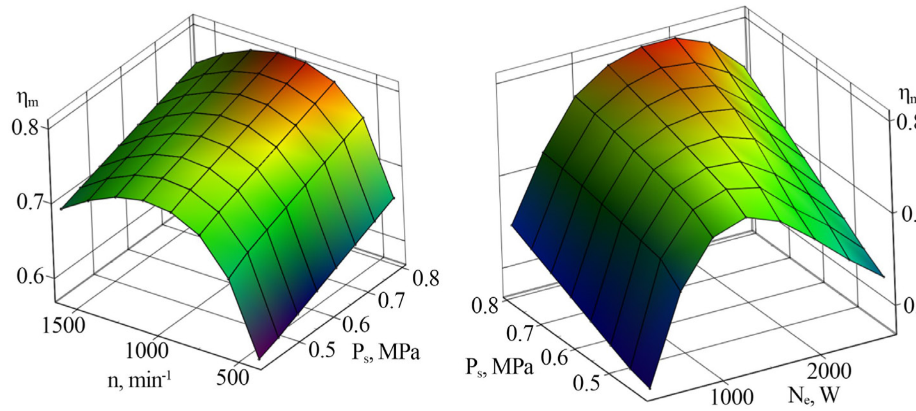


Fig. 4. The dependence of change in the mechanical efficiency of a rotary piston engine on operating parameters when operating on standard lubricating oil and with additives of the Multi-Tech-Conditioner antifriction additive (filled dots correspond to the condition for using the additive): *a* – dependence η_m on the engine speed at P_s=0.4 MPa; *b* – dependence η_m on the effective power of the engine at P_s=0.4 MPa; *c* – dependence η_m on the engine speed at P_s=0.6 MPa; *d* – dependence η_m on the effective power of the engine at P_s=0.6 MPa; *e* – dependence η_m on the engine speed at P_s=0.8 MPa; *f* – dependence η_m on the effective power of the engine at P_s=0.8 MPa

Table 3

Comparative evaluation of the efficiency of using anti-friction additive Multi-Tech-Conditioner in a rotary piston engine with a jointed cam movement mechanism

Operating pressure in the intake receiver P_s, MPa	Mechanical efficiency η_m	
	Without additive	Additive Multi-Tech-Conditioner
0.4	0.54...0.71	0.57...0.74
0.6	0.58...0.76	0.61...0.78
0.8	0.63...0.78	0.66...0.81



a *b*

Fig. 5. Influence of the operating parameters of the rotary piston engine on change in mechanical efficiency under the condition of adding the antifriction additive Multi-Tech-Conditioner: *a* – the effect of the engine speed and operating pressure in the inlet receiver on η_m; *b* – influence of the load on the engine and the working pressure in the inlet receiver on η_m

Thus, based on our experimental data, the rational operating range of a rotary piston engine is 65...75 % of its rated load. In this case, the rotor speed range corresponds to 63...70 %. It is also worth noting the increase in mechanical efficiency by 9.5 % with an increase in the working pressure in the receiver from 0.4 to 0.8 MPa. Based on this, it is necessary to select a rotary piston engine for a consumer of mechanical energy in such a way that most of its operation time falls within the recommended load range.

6. Discussion of results of experimental studies into the use of antifriction additive

An increase in engine speed leads to an increase in both losses to overcome friction forces (especially in the cam-articulated mechanism) and losses associated with pumping strokes. This is a consequence of an increase in the speed of the rubbing parts of the articulated-cam mechanism, as well as an increase in the gas-dynamic resistance of the gas exchange bodies. According to the obtained experimental data shown in Fig. 2, 3, the addition of Multi-Tech-Conditioner to standard rotary piston engine lubricating oil significantly reduces mechanical power loss. At the same time, unlike [9, 10], the additive stably provides a reduction in the power of mechanical losses over the entire range of engine speed changes at the level of 11.8 %. This is due to the use of a cam-articulated motion conversion mechanism, as well as the operating conditions of the tested engine and lubrication, which are different from those of internal combustion engines.

In accordance with the results of our study shown in Fig. 4, 5, the operating parameters and the selected load mode have a significant impact on the change in the mechanical efficiency of the engine. An increase in the working pressure of compressed air in the intake manifold contributes to an increase in mechanical efficiency (Table 3), which, first of all, is justified by a faster increase in effective power compared to the power of mechanical losses. At the same time, the addition of the Multi-Tech-Conditioner antifriction additive to the standard lubricating oil of a rotary piston engine contributes to an increase in mechanical efficiency up to 5.5 %.

Our results of studies on the influence of the operational parameters of the rotary piston engine on the change in mechanical efficiency make it possible to make an effective choice of the engine in accordance with the operational requirements of the energy consumer. At the same time, the presented experimental studies of the use of the anti-friction additive Multi-Tech-Conditioner are limited by operational and design parameters. The design limitations include the geometric dimensions of the movement conversion mechanism (the ratio of the piston stroke to the cylinder diameter – $S/D=0.4$) and gas exchange bodies. Operational limitations include operating modes (400...1500 min^{-1}) and operating air pressure range (0.4...0.8 MPa). It is also worth noting that the results obtained are limited to one value of the degree of filling of the working cylinder, which corresponds to the neutral position of the control cam.

The disadvantage of the current studies, according to the classical method for determining mechanical losses, is the absence of the process of expanding the working fluid in the cylinder and, accordingly, reducing the temperature of engine parts. Based on this, studies into the possible use of this Multi-Tech-Conditioner antifriction additive under conditions of negative temperatures are of considerable interest since it is known that the operation of most expansion machines is associated with them. In addition, additional analysis and experimental studies are required for the issue of reducing gas-dynamic losses in a rotary piston engine, which amount to 31.6 % of the total power losses. Additional studies are also required on the effect of the additive on viscosity characteristics at various operating temperatures and changes in the chemical composition of the oil. In the future, it is planned to conduct experimental studies using other commercial additives (LiquiMolyOilAdditiv, NanoEngineProtect&Seal, Hi-Gear, etc.).

7. Conclusions

1. The speed characteristics of change in the power of mechanical losses and friction losses of a rotary piston engine during operation with and without an antifriction additive in the speed range of 400–1500 min^{-1} have been determined. The positive effect of the addition of the Multi-Tech-Conditioner antifriction additive to lubricating oil on the change in the power of mechanical losses of a rotary piston engine with a cam-articulated movement conversion mechanism

has been established. The decrease in the total power of mechanical losses over the entire range of rotational speed change (400...1600 min^{-1}) was 11.8 % (from 262...865 W to 231...762 W). At the same time, the value of losses to overcome friction forces is 172...526 W, and the power loss to perform pumping strokes, depending on the speed, is approximately 25.6...31.6 % of the total power of mechanical losses.

2. It has been established that the use of the anti-friction additive Multi-Tech-Conditioner makes it possible to increase the mechanical efficiency of a rotary piston engine depending on the speed by 3.8–5.5 % over the entire range of operating pressure in the intake receiver. At the same time, based on the generalization of our experimental data on the change in mechanical efficiency, the most rational load ranges (65...75 % of the rated) and engine speeds (63...70 %) were identified.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

All data are available in the main text of the manuscript.

References

1. Mytrofanov, O., Proskurin, A., Poznanskyi, A. (2021). Research of rotary piston engine use in transport power plants. Transport Problems, 16 (1), 165–178. doi: https://doi.org/10.21307/tp-2021-014
2. Parsadanov, I. V., Belik, S. Yu. (2008). Mnogofaktornyy analiz mekhanicheskikh poter' v bystrokhodnom dizele s gazoturbinnym nadduvom. Dvigateli vnutrennego sgoraniya, 1, 34–37. Available at: https://repository.kpi.kharkov.ua/items/a4794f4f-f1ca-41ce-a49a-38f49b524b0b
3. Zeng-hong, S., Yu-cai, Y., Dan, Q. (2019). Research progress of Lubricant additives. LUBRICARING OIL, 34(05), 16-22.
4. Herdan, J. M. (1997). Lubricating oil additives and the environment – an overview. Lubrication Science, 9 (2), 161–172. doi: https://doi.org/10.1002/ls.3010090205
5. Syahir, A. Z., Masjuki, H. H., Yusoff, M. N. A. M., Ibrahim, T. M. (2022). Frictional Power Evaluation of Additive-Mixture in Trimethylolpropane Trioleate Oil using Single Cylinder Diesel Engine. IOP Conference Series: Materials Science and Engineering, 1244 (1), 012011. doi: https://doi.org/10.1088/1757-899x/1244/1/012011
6. Fan, B., Li, Z., Sun, A., Guo, Y., Qi, X., Liu, C. (2022). Experimental Study on Tribological Properties of Polymer-based Composite Nano-additives Suitable for Armored Vehicle Engine Lubricating Oil. MATEC Web of Conferences, 358, 01009. doi: https://doi.org/10.1051/matecconf/202235801009
7. Öğüt, H., Oğuz, H., Aydın, F., Ciniviz, M., Deveci, H. (2019). The effects of the use of vegetable oil based as engine lubrication oil on engine performance and emissions in diesel engines. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 42 (19), 2381–2396. doi: https://doi.org/10.1080/15567036.2019.1668507
8. Alqahtani, B., Hoziefa, W., Abdel Moneam, H. M., Hamoud, M., Salunkhe, S., Elshalakany, A. B. et al. (2022). Tribological Performance and Rheological Properties of Engine Oil with Graphene Nano-Additives. Lubricants, 10 (7), 137. doi: https://doi.org/10.3390/lubricants10070137
9. Varbanets, R. A., Ivanovskiy, V. G., Yakimenko, N. G. (2009). Rezul'taty ispytaniy raboty dizelya 4CH17.5/24 s prisadkoy k maslu «Multi-Tech Conditioner». Suchasni problemy dvyhunobuduvannia: stan, idei, rishennia: III Vseukrainskaya nauchno-tekhnicheskaya konferentsiya. Pervomaysk, 108–113.
10. Varbanets, R. A., Ivanovskiy V. G., Aleksandrovskaya, N. I., Kucherenko, Yu. N. (2014). Ispytaniya raboty dizelya 4CH17.5/24 s prisadkoy k maslu «multi-tech conditioner». Problemy khimmotolohiyi. Teoriya ta praktyka ratsionalnoho vykorystannia tradytsiynykh i alternatyvnykh palyvno-mastylnykh materialiv. Materialy V Mizhnarodnoi naukovo-tekhnichnoi konferentsiyi. Kyiv, 190–194.
11. Mytrofanov, O., Proskurin, A., Poznanskyi, A., Zivenko, O. (2022). Determining the power of mechanical losses in a rotary-piston engine. Eastern-European Journal of Enterprise Technologies, 3 (8 (117)), 32–38. doi: https://doi.org/10.15587/1729-4061.2022.256115
12. Testergebnisse. Available at: https://www.mtc-oil.com/referenzen-tests/
13. Mytrofanov, O. S., Shabalin, Yu. V., Biriuk, T. F., Yefenina, L. O. (2019). Pat. No. 120489 UA. Porshneva mashyna. No. a201902189; declareted: 10.09.2019; published: 10.12.2019. Available at: https://base.uipv.org/searchINV/search.php?action=viewdetails&IdClaim=263906