Article citation info:
Korabay R, Kushaliev D, Zabiyeva A, Samenov G, Radjibayev D. Improving a spring liner design for a cylinder piston group. Diagnostyka. 2025;26(2):2025208. https://doi.org/10.29354/diag/203686.

DIAGNOSTYKA, 2025, Vol. 26, No. 2

e-ISSN 2449-5220
DOI: 10.29354/diag/203686

IMPROVING A SPRING LINER DESIGN FOR A CYLINDER PISTON GROUP

Rizabek KORABAY [1], Dauren KUSHALIEV [1,*], Aliya ZABIYEVA [1,*], Galymzhan SAMENOV [1], Davran RADJIBAYEV [2]

[1] Eurasian National University, Faculty of Transport and Energy, Kazakhstan
[2] Faculty of Railway Transport Engineering, Tashkent State Transport University, Uzbekistan
[*] Corresponding authors, e-mail: aliya.zhakupovazabieva@gmail.com, kushaliyev_dk@enu.kz

Abstract

The engine is one of the most important and complex parts of the car. Most of the breakdowns occur in the piston group of the internal combustion engine, especially in the compression rings. This article presents a new design for an innovative repair kit for transport equipment units. Article considers new principles and effects for reducing friction in vehicle units. The main difference of the new solution is the use of spring rings instead of simple installation of compression piston rings. The main goal of functional tuning is to increase the strength and technical indicators of friction between piston rings and cylinder liner. New technology decreases the natural wear of piston rings and the integrity of piston grooves in which the rings are installed. Moreover, new kit improves seals and increases shock absorption when the combustible mixture ignites. Suggested spring kit is tested in virtual environment with all with external factors and processes that can affect the operation of the spring. Based on the results of the experiments and mathematical calculations, suggested kit can work under the real working conditions without any deformation and losing functionalities.

Keywords: innovative repair kit, spring inserts, transport, tribo-coupling technology, new principles and effects, friction reduction, reliability.

List of Symbols/Acronyms

65G – mark of the steel;
AISI 1066 - mark of the steel;
CPG – Cylinder Piston Group;
FFE – Full – Factorial Experiment.
D1 - Wire diameter
D2 - The diameter of the inner circle
n - Number of turns
L3 - The height of the spring in the compressed state
Y - The "response" of the function
x_n – Factors

1. INTRODUCTION

The engine is the most important and complex part of the car, responsible for the efficiency, reliability and environmental friendliness of the car. A considerable part of all car breakdowns is related to the engine. It is known that the car engine has a low efficiency, and the main losses occur from the connection of the piston and cylinder, which can reach about 40-50% [1, 2, 3, 16, 19]. These results are caused by friction losses and engine oil consumption [7, 17]. According to research, about 15% of the fuel is consumed by the engine to overcome friction between the piston rings and the cylinder liner [5, 6, 15]. As a result of natural wear of connections and violations of the adjustments of the main engine systems, unevenness of cylinder operation increases to 25-30%, and energy efficiency decreases to 35%. In addition, there is an increase in fuel consumption, which can reach about 25%, excluding the deterioration of other indicators [4].

Piston rings have a vital role in the operation of the piston-cylinder joint [18]. It is important to maintain free movement of their grooves inside the piston to remain in contact with the cylinder [5]. Sticking of the rings in the piston is usually caused by the accumulation of combustion products or lubricating oil, which can lead to engine failure and increase of the friction loss [17, 18, 20].

Radial movement of the rings leads to wear of the ring and the lower surface of the ring recess. This can lead to gas breakthrough and coking of the engine oil. Then the piston rings will completely lose their sealing properties [6, 27, 30]. See Fig. 1.

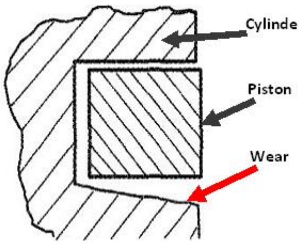

Fig. 1. Wear of the bottom surface of the ring recess

Received 2025-03-05; Accepted 2025-04-03; Available online 2025-04-05

According to the research, the average age of cars in operation in Kazakhstan is 22 years. This means that most parts, especially engine parts such as piston rings, are expected to deteriorate or wear out [7, 28, 29, 31].

This situation is the main reason for providing a solution for repair and extension of service life of piston design. The increasing of the working life of the engine parts is one of the most wanted purposes for organizations [8]. The solution is based on using the spring liners that will press piston rings to the piston ends to increase service life and avoid destruction of the lower part of the piston edge where the rings are installed. In this case, a "ratchet effect" occurs - forced rotations only in one direction depending on the direction of spring winding [9]. Moreover, during operation, the contact line on the working surfaces is constantly changing, which leads to a decrease in their wear.

2. METHOD

First, a 2D model was drawn on the AutoCad platform, where basic positions of the spring and piston rings in the piston were determined. There was drawn general view of the piston with and without a repair kit. At this stage, the exact dimensions and material for the spring were not approved. This allows to think over all the nuances and questions that would arise during the creation of a 3D model in the simulator. See figures 2 and 3.

Fig. 2 shows the piston design with the place for installing the piston rings and spring liners. The location of the piston rings has remained unchanged, while the spring will be installed between the two rings, and the location of the spring has been machined.

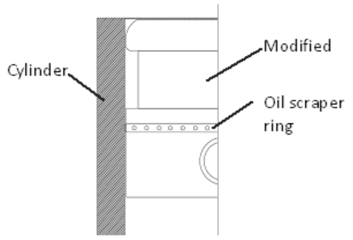

Fig. 2. the design of the modified piston for the spring

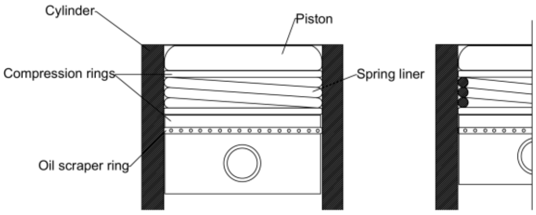

Fig . 3. Piston design with repair kit

The next step is to select the material and size for the spring. The 65G steel was chosen as the material. It has international analogues (65Mn, 1066, 566, 080A67) [8, 9, 10, 14]. This type of steel is common in the manufacture of springs and parts for internal combustion engines. In the experiment, it was used some characteristics of the analogue, AISI 1066 steel, due to the lack of complete data on 65G steel. All metal characteristics were entered manually because 65G steel and its analogues do not exist in the SolidWorks database. In the following table it is possible to see the detailed characteristics used for the experiment in the SolidWorks environment.

Table 1. Properties of metal

Quantity	Value	Unit
Thermal expansion	10 - 10	e^{-6}/K
Thermal conductivity	25 - 25	W/m·K
Specific heat	460 - 460	J/kg·K
Melting temperature	1450 - 1510	°C
Density	7850	kg/m^2
Resistivity	0.55 - 0.55	$\mathrm{Ohm} \cdot \mathrm{mm}^2/m$
Poissons Ratio	0.27-0.30	(Typical For Steel)
Elastic Modulus	190-210	(GPa)
Tensile Strength	1158	(MPa)
Yield Strength	1034	(MPa)
Elastic Modulus	190-210	(GPa)

The main dimensions for the spring were selected in accordance with the dimensions of the piston group of the Hyundai Accent G4FG-5 internal combustion engine. Some sizes were measured manually due to the lack of information in open sources. The piston group of this car was chosen because the car has been one of the most common cars in Kazakhstan since 2010 [11, 21, 22, 26]. And a possible repair kit may be relevant for repairing the piston group of these cars after the expiration of the service life of some parts.

Fig. 4. Piston of Hyundai Accent 1.6l made by Mobis company (original picture was made by the author)

After defining the drawings, a 3D model was created in SolidWorks.

Fig. 5. Spring model

This table represents the main dimensions of the spring.

Table 2. Spring dimensions

D1	1.4mm	Wire diameter
D2	72mm	The diameter of the inner circle
n	1	Number of turns
L3	3.5mm	The height of the spring in the compressed state

The wire diameter and the number of turns were chosen experimentally to determine the most durable spring design. With many turns, the spring would not fit the gap between the rings, similarly with the thickness of the wire itself. The minimum height of the spring when the turns touch each other is 3.5 mm, which is less than the distance between the grooves of the piston rings. It is important because spring increases in size during the heating and needs space for expansion. The diameter of the spring itself also does not exceed the diameter of the piston to avoid contact of the spring with the cylinder mirror.

The main external factors, envisaged in the experiment, affecting the spring will be the temperature during fuel combustion and the compression force of steam gases. During the experiment, 10.5 N of compression force was applied to the spring. This compression is the working pressure for the piston group of the Hyundai Accent car with the G4FG-5 1.6 liters. Without changing the compression force of 10.5 N, the spring temperature was changed in the range from 0 to 350 degrees Celsius to simulate the real operating environment of the piston and spring inside the internal combustion engine [12, 13, 21, 22, 23, 24]. Thus, it was possible to determine the output stress and spring movements under different temperature conditions with constant compression pressure.

After creating the model, the polygonal mesh of the spring was created using a data processing method. The following image shows the main parameters for creating the mesh.

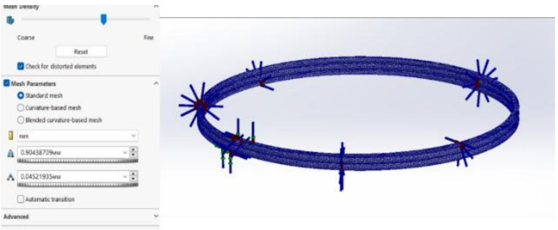

Fig . 6. Spring representation with mesh parameters

Stage of making the experiment.

The main factors were:

- temperature, °C;
- thermal conductivity coefficient, m·°C;
- specific heat capacity, J/kg·°C.
- stress (N/m^2) or output data (Y).

During the experiment, the spring was subjected to a compression force of 10.5 N to simulate compression in the engine cylinder [23, 24, 25]. Then there were applied the experimental temperature values from 0 to 300 °C with the corresponding values of the thermal conductivity coefficient and specific heat capacity taken from the tabular data.

3. RESULTS

This section presents the results of the experiment conducted in SolidWorks.

The following table shows the results of the stress and displacement of the spring along the vertical axis under the influence of factors (temperature, thermal conductivity coefficient, specific heat capacity, J/kg·°C) affecting the results of the study.

Table 3. Experiment results

	Temperature	Stress 10^8 (N/m^2)	Displacement according to vertical axis (mm)
1	24	1.079	0
2	100	2.246	-0.013 – 0.027
3	150	4.064	-0.014 – 0.046
4	200	5.883	-0.015 – 0.064
5	250	7.701	-0.016 – 0.078
6	300	9.520	-0.018 – 0.086

It can be seen that the stress and displacement increase proportionally to the increase in temperature. You can also see the expansion of the metal under the influence of temperature.

Several results are presented below in graphical form fig. 7-9.

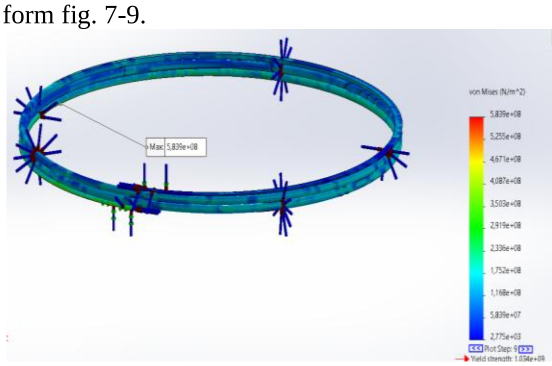

Fig . 7. Results of stress at operating values of compression and temperature of 200 °C.

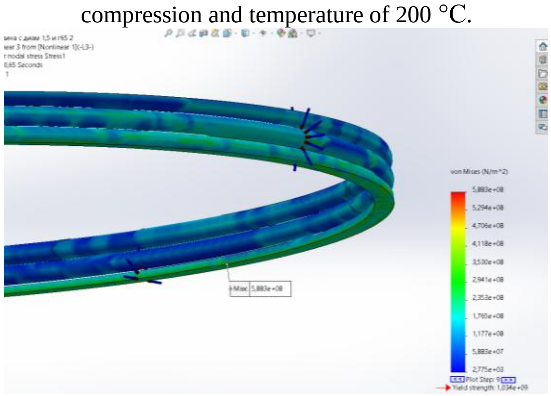

Fig . 8. Results of stress at operating values of compression and temperature of 200 °C

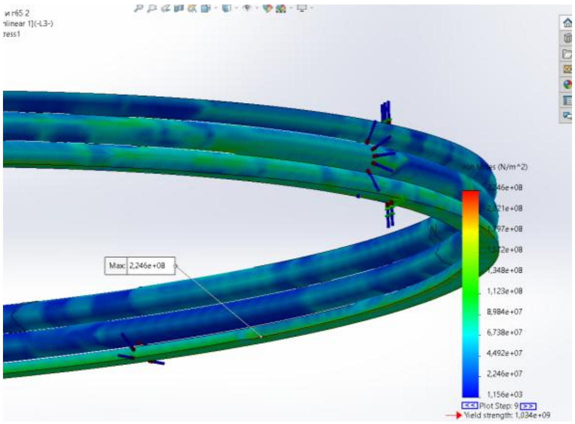

Fig. 9. Results of stress at operating values of compression and temperature of 100 °C

The results show that the stress is not distributed evenly, but it increases from the top of the spring to the bottom. The peak stress values appear at the corners of the bottom of the spring.

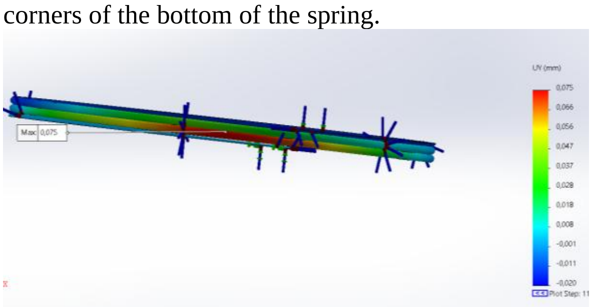

Fig. 10. Results of displacement at operating values of compression and temperature of 200 °C

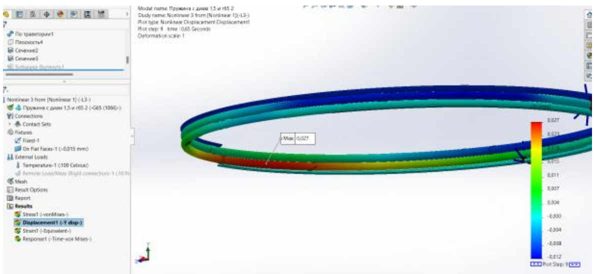

Fig . 11. Results of displacement at operating values of compression and temperature of 100 °C

Based on the results of the movement, it can be said that the main movement occurs in the central coil of the spring, namely from the end of the coils.

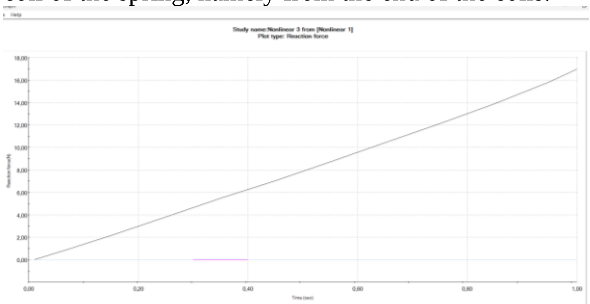

Fig . 12. Applied reaction force to the spring

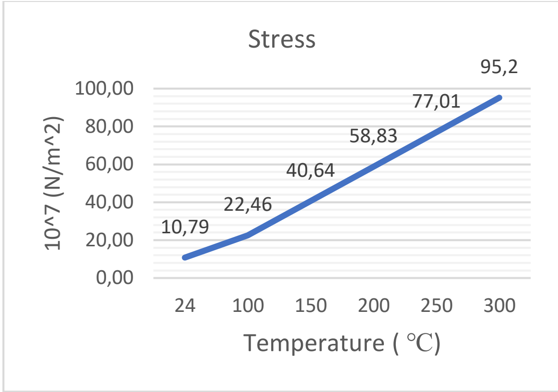

Fig . 13. Changes of stress results depending on applied temperature

From this picture you can see that the graph of voltage depending on the applied temperature is linear.

The data obtained from the experiment were used for mathematical calculation of adequacy.

To create a mathematical model of the object under study there were used methods of experimental planning theory.

In general, the mathematical description of the experiment can be represented in the following form. The property of the object (*Y*) depends on several (x_1, $x_{2,}$ $_{\dots}x_n$) and this will allow to clarify the nature of this dependence.

$$Y = F_j\,(x_1, x_2, \dots x_n)\ , \qquad (1)$$

where the value *Y* is called the “response” of the function, and the dependence is

$Y = F_j\,(x_1, x_2, \dots x_n)$ – "response function";

$x_1, x_2, \dots x_n$ - Variables are factors of the experiment.

It is considered that the equation which is connecting the response function with the factors as a mathematical model of the experiment – the regression equation.

The regression equation of interest with the three variables can be written in the form of the following polynomial

$$Y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{123}x_1x_2x_3, \qquad (2)$$

Where

b_0 – is the free coefficient of the regression equation;

b_i – linear coefficients of the equation;

b_{ij}–paired coefficients or effects of paired interaction;

b_{123} – is the effect of the interaction of three factors.

The absolute value of the coefficients indicates the degree of influence of a given factor on the response function, and the sign in front of the coefficient indicates the direction of the factor's action.

Let's proceed to the mathematical formalization and coding of variables (factors).

The main factors of the experiment:

- temperature, °C;
- thermal conductivity coefficient, m·°C;
- specific heat capacity, J/kg·°C;

- stress (N/m^2)) or output data (Y).

List of factors included in the experiment.

Table 4.

№	Factor name	Marking	Unit	Range
1	Temperature	x_1	℃	50 - 300
2	Coefficient of thermal conductivity	x_2	m·℃	34 - 37
3	Specific heat capacity	x_3	J/kg·℃;	440 - 525

Let's test a three-dimensional experiment where each factor has two levels.

Table 5. Coding of factors

Factors	x_i	x_1	x_2	x_3
Upper level	$x_{i\ up}$	300	37	525
Lower level	$x_{i\ low}$	50	34	440
Base level	$x_{i\ 0}$	175	35.5	482.5
Step (interval) of variation	Δx_i	125	1.5	42.5

The main advantage of a factorial experiment is that all factors are varied simultaneously in the experiment. This results in the dispersion in the estimate of the regression coefficients being N times smaller than the experimental error.

Below we present (table 6) the matrix of the full-factorial experiment (FFE) design 2^3 with the included dummy variable x_0.

Regression equation is found in the form (2). Below, the values of the coefficients for the regression equation are calculated using the formula (see the manual):

$$b_j = \frac{1}{N}\sum_{i=1}^{N} x_{ji} y_i \ , j = \overline{1, k}\ . \quad (3)$$

Take: $b_0 = 4.209$, $b_1 = 0{,}673$, $b_2 = 0{,}9831$, $b_3 = 2{,}5834$, $b_{12} = 0{,}9424$, $b_{13} = 0{,}2369$, $b_{23} = 0{,}8354$, $b_{123} = -0{,}0156$.

The representation of regression equation in coded form:

$$Y = (4{,}21 + 0{,}673x_1 + 0{,}98x_2 + 2{,}5834x_3 + 0{,}9424x_1x_2 + 0{,}2369x_1x_3 + 0{,}8354x_2x_3 - 0{,}02x_1x_2x_3)*10^8 \quad (4)$$

The obtained coefficients of equation (4) are tested for significance using Student's t-test. To do this, we additionally made three more experiments, for example, with values

y: $y_1^0 = 3.166$; $y_2^0 = 4.9735$; $y_3^0 = 4.5$.

From these data: $\overline{y^0} = \frac{1}{3}\cdot 12.64 = 4.21$

An experiment is considered reproducible if the variance of the output parameter Y_j is homogeneous at each point in the factor space.

The variance of reproducibility is calculated by the formula

$$S_{\text{repro}}^2 = \frac{1}{k-1}\sum_{u=1}^{3}\left(y_u^0 - \overline{y^0}\right)^2 = \frac{10^{16}}{2}\cdot 1.757 = 0.8785$$

$$S_{\text{repro}} = 0.94\cdot 10^8$$

Let us determine the accuracy of the coefficients of equation (4):

$$S_{b_j} = \frac{1}{\sqrt{N}}\cdot S_{\text{repro}} = \frac{1}{\sqrt{8}}\cdot 0{,}94\cdot 10^8 = 0{,}3\cdot 10^8$$

Now we evaluate the significance of the coefficients of equation (4) using the Student's criterion:

$$\Delta b_j = t_{pf}\cdot S_{b_j}, \quad \text{f=N(k-1)}, \quad \left|b_j\right| = \Delta b_j$$

$$t_0 = \frac{|b_0|}{S_{b_0}} = \frac{4.21}{0.3} = 14.03; \quad t_1 = \frac{|b_1|}{S_{b_0}} = \frac{0.673}{0.3} = 2.243; \quad t_2 = \frac{|b_2|}{S_{b_0}} = 3.27;$$

Table 6.

№ experiment	x_0	Impact Plan							Results of experiment	Theoretical results based on the equation
		x_1	x_2	x_3	x_1x_2	x_1x_3	x_2x_3	$x_1x_2x_3$		
1	+	-	-	-	+	+	+	-	1.079	1.65
2	+	+	-	-	+	-	+	+	1.876	3.0
3	+	-	+	-	-	+	-	+	1.3	0.2
4	+	+	+	-	+	-	-	-	2.246	3.45
5	+	-	-	+	-	-	-	+	4.064	3.37
6	+	+	-	+	+	+	-	-	5.883	6.65
7	+	-	+	+	-	-	+	-	7.701	6.97
8	+	+	+	+	+	+	+	+	9.520	10.25

$$t_3 = \frac{|b_3|}{S_{b_0}} = 8.6;\ t_{12} = \frac{|b_{12}|}{S_{b_0}} = 3.14;\ t_{13} = \frac{|b_{13}|}{S_{b_0}} = 0.79;$$

$$t_{23} = \frac{|b_{23}|}{S_{b_0}} = 2.78;\quad t_{123} = \frac{|b_{123}|}{S_{b_0}} = 0.07.$$

The tabular value of the Student's criterion for the confidence probability p = 0.95 and the number of degrees of freedom f=16 is equal to:

$$t_{0.95;16} = 2.13$$

Therefore, the regression equation (4) will have the form

$$Y = (4{,}21 + 0{,}67x_1 + x_2 + 2{,}58x_3 + 0{,}94x_1x_2 + 0{,}83x_2x_3)\cdot 10^8 \qquad (5)$$

According to Fisher's criterion

$$F_{calc} = S_l^2/S_{cre}^2$$

where

$$S_l^2 = \frac{1}{N-(k+1)}\sum_{j=1}^{N}(y_j^{p} - y_j^{э}),$$

k – number of parallel determinations,
y_j^p – calculated values according to equation (5),
$y_j^э$ – experimental data (output, experimental results).

Then,

$$S_l^2 = ¼\cdot 6.57 = 1.64,$$

$$F_{calc} = \frac{1{,}64}{0{,}88} = 1{,}86,$$

$$f_{cre} = N(k-1) = 8\cdot 2 = 16,\ f_{ad} = N - (k+1) = 8 - 4 = 4$$

Table value of Fisher's criterion for

$$p = 0{,}05;\ f_1 = 4;\ f_2 = 16 \text{ equal}$$

$$F_{1-p}(f_1, f_2) = 3.0.$$

Thus, $F_{calc} < F_{tabel}$,, therefore, the regression equation (5) is considered adequate.

Based on the calculation results, the following conclusions are:

1. In the obtained regression equation, all factors included in the experiment have positive (coefficients with the "+" sign) influence. That is, with an increase in their value, the value of Y increases.
2. Factor x_3 has a greater influence on the experiment than factors x_2 and x_1 (3.7 times or 30% and 2.6 times or 38.5%, respectively).
3. Factors x_2 *and* x_1 separately have a weaker effect than when they act simultaneously, since the term $x_2 \cdot x_1$ has a positive value. Similar reasoning applies to factors x_2 *and* x_3.
4. The coefficients of the terms $x_3 \cdot x_1$ and $x_1 \cdot x_2 \cdot x_3$ are insignificant. Therefore, the simultaneous effects of these combinations of factors are not significant in the experiment.

4. DISCUSSION

Based on the obtained results it can be said that the proposed model is adequate and applicable in real life. The viability of the model was calculated using a mathematical model and tested in the simulator. The model withstands the effects of the applied factors and remains stable. The next step may be the manufacture of a full-size physical prototype for testing on a real stand or an internal combustion engine.

During the tests on the SolidWorks simulator, some difficulties arose. The program database did not contain characteristic data on the metal we selected. This could affect the accuracy of our experiment, since the data was entered manually.

5. CONCLUSION

Based on the results of the test conducted in the SolidWorks simulator and the mathematical model for the adequacy of the model, it can be said that the proposed solution is a working solution for improving the operation of the CPG.

The results showed that an increase in the value of the influencing factors proportionally increases the voltage value. Specific heat has a greater effect on the experiment than others. The factors individually affect less than when exposed simultaneously, with the exception of $x_3 \cdot x_1$ and $x_1 \cdot x_2 \cdot x_3$ combinations.

The next goal is to conduct testing on a real stand or an internal combustion engine with the installation of a spring liner.

Source of funding: *This research received no external funding.*

Author contributions: *research concept and design, A.Z.; Collection and/or assembly of data, G.S. Data analysis and interpretation, R.K.; Writing the article, D.R.; Critical revision of the article, D.K.; Final approval of the article, A.Z., G.S., R.K., D.R., D.K.*

Declaration of competing interest: *The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.*

REFERENCES

1. Harsha Rajput, Ashok Atulkar, Rajkumar Porwal, Optimization of the surface texture on piston ring in four-stroke IC engine. Materials Today: Proceedings. 2021;44(1):428-433. https://doi.org/10.1016/j.matpr.2020.09.752.
2. Tung SC, Mc Millan ML. Automobile tribology overview of current advanced and challenges for the future. Tribology International. 2004;37:517-536. https://doi.org/10.1016/j.triboint.2004.01.013.
3. Kellaci A, Mazouzi R, Khelidj B. The effect of lubricant rheology on piston skirt/cylinder contact for an internal combustion engine. Mechanika. 2010;1(81):30-36. https://doi.org/10.5755/J01.MECH.81.1.9765.
4. Grabon W, Pawlus P, Sęp J. Tribological characteristics of one-process and two-process cylinder liner honed surfaces under reciprocating sliding conditions. Tribol. Int. 2010;43:1882–1892. https://doi.org/10.1016/j.triboint.2010.02.003.

5. Rozario A, Baumann C, Shah R. The influence of a piston ring coating on the wear and friction generated during linear oscillation. Lubricants. 2019;7. https://doi.org/10.3390/lubricants7010008.
6. Wong W, Tung C. Overview of automotive engine friction and reduction trends–effects of surface, material, and lubricantadditive technologies. Friction. 2016;4:1–28. https://doi.org/10.1007/s40544-016-0107-9.
7. Taylor CM. Automobile engine tribology-design considerations for efficiency and durability. Wear. 1998;221:1–8. https://doi.org/10.1016/S0043-1648(98)00253-1.
8. Voznitsky IV, Punda AS. Marine internal combustion engines. Supreme Audit Chamber of the Republic of Kazakhstan. 2010. https://www.gov.kz/memleket/entities/esep?lang=en.
9. Gubarevych O, Gerlici J, Gorobchenko O, Kravchenko K, Zaika D. Analysis of the features of application of vibration diagnostic methods of induction motors of transportation infrastructure using mathematical modeling. Diagnostyka. 2023; 24(1):1–10. https://doi.org/10.29354/diag/161308.
10. Xia Y, Pang J, Yang L, Zhao Q, Yang X. Nonlinear numerical and experimental study on the second-order torsional and lateral vibration of driveline system connected by cardan joint. Journal of Vibration and Control. 2020;26(7–8):540–551. https://doi.org/10.1177/1077546319889846.
11. Erokhin M, Pastukhov A, Golubev I, Kazantsev S. Theoretical basis of justification of electromechanical hardening modes of machine parts. Engineering for Rural Development. 2020:147:152. https://doi.org/10.22616/ERDev.2020.19.TF032.
12. Supreme Audit Chamber of the Republic of Kazakhstan. 2025. https://www.gov.kz/memleket/entities/esep?lang=en
13. Tian W, Zhang J, Zhou K, Chen Z, Shen Z, Yang X, Cong Q. Bionic design and optimization of the wear-resistant structure of piston rings in internal combustion engines. Lubricants. 2023;11:484. https://doi.org/10.3390/lubricants11110484.
14. Taylor CM. Automobile engine tribology-design considerations for efficiency and durability. Wear. 1998;321(1):1-8, https://doi.org/10.1016/S0043-1648(98)00253-1.
15. Knauder C, Allmaier H, Sander DE, Sams T. Investigations of the friction losses of different engine concepts. Part 1: A combined approach for applying subassembly-resolved friction loss analysis on a modern passenger-car diesel engine. Lubricants. 2019;79. https://doi.org/10.3390/lubricants7050039.
16. Liu J, Zhang Y, Liao B. A review on preparation process and tribological performance of coatings for internal combustion engine piston ring. Advances in Mechanical Engineering. 2023;15(5). https://doi.org/10.1177/16878132231175752.
17. Bedajangam SK, Jadhavb NP. Friction losses between piston ring-liner assembly of internal combustion engine: A review. international journal of scientific and research publications. 2013;3(6).
18. Ahmed Ali MK, Xianjun H, Fiifi Turkson R, Ezzat M. An analytical study of tribological parameters between piston ring and cylinder liner in internal combustion engines. Proceedings of the Institution of Mechanical Engineers. Part K: Journal of Multi-body Dynamics. 2016;230(4):329-349. https://doi.org/10.1177/1464419315605922.
19. Agostino VD, Maresca P, Senatore A. Teoretical analysis for friction losses minimization in piston rings. International Conference on Tribology. 2006.
20. Arystanov Z, Togizbayeva B, Kenesbek A, Mambetov D, Kinzhebayeva A. Study of electric and hybrid vehicles in the form of alternative transport in Kazakhstan. Environmental Progress and Sustainable Energy. 2023;43(3):e14334. https://doi.org/10.1002/ep.14334.
21. Burdzik R, Simiński D, Kruszewski M, Niedzicka A, Gąsiorek K, Zabieva AB, Mamala J, Dębicka E. Designing and planning of studies of driver behavior at pedestrian crossings using whole-vehicle simulators. Appl. Sci. 2024;14:4217. https://doi.org/10.3390/app14104217.
22. Kushaliev DK, Zabieva AB, Balgynova AM, Burdzik R, Alipbaev ZR. Diagnostics of an innovative repair kit for transport equipment units. Diagnostyka. 2024;25(1):2024106. https://doi.org/10.29354/diag/176291.
23. Sherov K, Absadykov B, Sikhimbayev R, Togizbayeva B, Esirkepov A. Investigation of the stress-strain state of components of a hydraulic impact device. 2023;1. https://doi.org/10.32014/2023.2518-170X.274.
24. Ischuka O, Togizbaeva B. Technique of drawing up for the daily plan-schedule of station operating. Transport Means - Proceedings of the International Conference. 2017:137–140.
25. Deuszkiewicz P, Dziurdź J, Fabiś P. Modeling the influence of engine dynamics on its indicator diagram. Sensors. 2021;2(23):7885. https://doi.org/10.3390/s21237885.
26. Dąbrowski Z, Deuszkiewicz P, Dziurdź J. Proposition of the vibroacoustic diagnostic methodology of testing toothed gears of marine drives. Journal of Marine Engineering and Technology. 2017;16(4):386-391. https://doi.org/10.1080/20464177.2017.1364838.
27. Łapińska A, Grochowska N, Cieplak K. Architecture influence on acoustic performance, EMI shielding, electrical and thermal, properties of 3D printed PLA/graphite/molybdenum disulfide composites. Materials & Design. 2024;245:113241. https://doi.org/10.1016/j.matdes.2024.113241.
28. Merkhatuly N, Iskanderov AN, Balmagambetova LT, Togizbaeva BB. Reactions of (-)-estafiatin with acidic reagents. Russian Journal of Organic Chemistry. 2013;49(9):1405–1406. https://doi.org/10.1134/S1070428013090315.
29. Khromova G, Radjibaev D, Zabiyeva A, Kenesbek A, Mavlanov A. Calculation of the main parameters of the two-line helical traction transmission of an electric locomotive based on diagnostic parameters. Applied Sciences-Basel. 2025;15(4):1730. https://doi.org/10.3390/app15041730.

Rizabek KORABAY is a PhD student in the Faculty of Transport and Energy at Eurasian National University, Kazakhstan, received a Master's degree in Engineering and Digital Science in Nazarbaev University, Kazakstan. He is an author or co-author of the scientific papers. Overall, he has a 5 papers in journals recommended by the Higher Attestation Commission of the Republic of

Kazakhstan, in Kazakh and international journals and in International Conference.
e-mail: rizabekkorabay@gmail.com

Kushaliyev DAUREN is currently working as an acting associate professor at the department of “Transport, transport equipment and technology”, candidate of technical sciences, Ph.D. of the L.N. Gumilyov Eurasian National University. Author of more than 65 scientific articles, in the foreign journal Clarivate Analytics - 2, journal included in the SCOPUS database - 7, patent for an invention of the Russian Federation - 1, Eurasian patent for an invention - 1, innovative patent of the Republic of Kazakhstan - 4, monographs - 5. Scientific interests: Since 2010, he has been dealing with the problems of tribology and tribotechnics in relation to components and mechanisms of transport technology and technological equipment.
e-mail: radjibaev_railway@tstu.uz

Aliya ZABIYEVA is an associate professor professor in the Faculty of Transport and Energy at Eurasian National University, Kazakhstan. She is an author or co-author of books and more than 30 scientific papers. Authored over 30 publications, including: in journals recommended by the Higher Attestation Commission of the Republic of Kazakhstan, in Kazakh and international journals, in scientific conferences, one monograph. She is a researcher in the field of engineering, railway transport and participated in many international projects under the Erasmus + program.
e-mail: aliya.zhakupovazabieva@gmail.com

Candidate of Technical Sciences, Associate Professor **Samenov GALYMZHAN** was born in 1978 in Kazakhstan. He graduated from Казахского национального технического университета имени К.И.Сатпаева. Since 2022, he has been serving as the docent of the Faculty of Energy and Transport at Eurasian National University.
e-mail: samenov_gk@enu.kz

Doctor of Technical Sciences, Associate Professor **Rajibayev Davran OKTAMBAYEVICH** was born in 1987 in Tashkent. He graduated from Emperor Alexander I St. Petersburg State Transport University, defended his Candidate of Technical Sciences dissertation in 2012, and his Doctor of Sciences dissertation in 2024. Since 2020, he has been serving as the Dean of the Faculty of Railway Transport Engineering at Tashkent State Transport University.
e-mail: rizabekkorabay@gmail.com