Article citation info:
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.

DIAGNOSTYKA, 2024, Vol. 25, No. 1

e-ISSN 2449-5220
DOI: 10.29354/diag/176291

DIAGNOSTICS OF AN INNOVATIVE REPAIR KIT FOR TRANSPORT EQUIPMENT UNITS

Dauren Kaysarovich KUSHALIEV [1], Aliya Batyrbekovna ZABIEVA [1], Akzharkyn Merekeevna BALGYNOVA[2], Rafał BURDZIK [3,*], Zhasulan Ratkanovich ALIPBAEV [1]

[1] Eurasian National University, Faculty of Transport and Energy, Kazakhstan
[2] K. Zhubanov Aktobe Regional University Department of Oil and Gas Business, Kazakhstan
[3] Silesian University of Technology, Faculty of Transport and Aviation Engineering, Krasińskiego 8, 40-019 Katowice, Poland
[*] Corresponding author, e-mail: rafal.burdzik@polsl.pl

Abstract

The article presents the transmission of a truck, where innovative repair kits of the driveshaft crosspiece are used. The crosspiece is an element of the transmission, and transmits all the torque from the gearbox to the wheels of the car, therefore it is a heavily loaded part. A mathematical model has been developed that describes in detail the process of changing the size of a movable conical spring insert in a sliding bearing used in the mechanism of the cardan shaft crosspiece. The innovative repair kit is designed to improve performance by introducing an elastic intermediate element into the bearing. This element is a movable insert in the form of a helical or conical spring, and its compressible force is adjustable. This creates a tight seal on the working surfaces, preventing oxidative processes and activation of microplastic deformation of the surface.

Keywords: innovative repair kit, spring inserts, car suspension, crosspieces.

List of Symbols/Acronyms

65G – spring wire made of steel;
H5 – hole;
p4 – shaft;
CTT – chemical and thermal treatment;
HRC – hardness;
AH-348A – welding flux;
UD-209 or A-547U – installation for arc surfacing;
FAFAT – finishing antifriction-free abrasive treatment;
ISTM – interchangeability, standardization and technical measurements,

1. INTRODUCTION

Currently, a large number of foreign-made trucks have appeared on the roads of Kazakhstan. [1]. Many of them require some kind of repair after a certain period of operation. The service cycle of a truck turns out to be, as a rule, very short. This is result of difficult road conditions, poor fuel quality, not always high-quality oil, and illiterate maintenance.

A huge number of types and models of trucks, mainly of previous years of production, need repair of transmission units and aggregates, but the practical absence of a network of branded service sharply exacerbates the problem of repair. Often there is no one and nowhere to make it, even having the opportunity to purchase the necessary spare parts, or vice versa. Basically, these are cars produced more than 10 – 15 years ago [2], which could be operated if there was an opportunity to repair them.

There are many reasons why the repair of trucks turns into a serious problem in Kazakhstan. This is mainly due to the massive appearance of foreign-made cars in Kazakhstan, when the necessary repair facilities, a network of service stations and workshops have not yet developed.

One of the urgent tasks facing organizations operating automotive and automotive equipment is to extend the service cycle of used parts. [3]. Including the replacement of parts of the main structure with more reliable and maintainable ones. However, this is associated with significant difficulties, since this type of repair is possible only under certain wear criteria.

The transmission is a complex consisting of a number of components and assemblies. And when it comes to repairing the transmission, the full restoration of these mechanisms is sometimes almost more difficult than the sum of traditional operations – surfacing the crosspiece, surfacing the spline part of the driveshaft, etc. Specialized equipment is required, the complexity and accuracy of execution are very high.

Received 2023-10-13; Accepted 2023-12-04; Available online 2023-12-22

2. METHODS

When transferring torque from the gearbox (gear box) to the gearboxes of the driving wheels, it is necessary to ensure the mutual movement of the nodes, taking into account the fluctuations of the power unit and the movement of the gearboxes, when the car is moving. For this purpose, crosspieces [1, 2, 3, 4, 5] are used, which provide the transmission of torque when the shaft elements are deflected by 15 degrees. The crosspiece connects two forks pivotally; at the same time, the spikes of the crosspiece enter the holes of the forks. Needle bearings are installed on the spikes, the housings of which are pressed into the holes of the forks. The crosspiece is an element of the transmission and transmits all the torque from the gearbox to the driven wheels of the car, therefore it is a heavily loaded part. Depending on the nature of wear, the crosspieces are distributed according to the following defects: crosspieces having only dimensional wear, crosspieces having dimensional wear in combination with crumpling of spikes, crosspieces having dimensional wear in combination with crumpling and volumetric deformation (ovality, taper), crosspieces not subject to restoration.

The dimensional wear is 0.05-0.15 mm, the depth of dents is 0.1-0.6 mm. Since the crosspieces are installed in the forks of the cardan shaft joints on needle bearings, dents on the surface are formed from needle rollers.

The following technical requirements are imposed on the cardan shaft crosspieces that are being repaired. The crosspieces are not accepted for repair in the presence of one of the following defects [6,7,9] cracks; discoloration; ovality and taper over 1 mm; when the spikes are worn more than 1.3 mm in diameter.

The tribo-coupling shown in Figure 1 consists of a shaft 1, an outer ring 2 and a special insert 3 made in the form of a spiral coil spring placed between the shaft and the outer ring. The movable conical insert in the form of a spiral helical spring has a cone angle from 1 to 5 degrees. In this case, the diameter of the spring wire (marked as d) is equal to half the difference between the shaft diameter (D) and the insert hole diameter (D+2d) [10, 11, 12]. Please note that this insert is mounted to provide resistance and pressure at the edges and between the inner and outer surfaces to ensure the "ratchet effect" is consistently present [14].

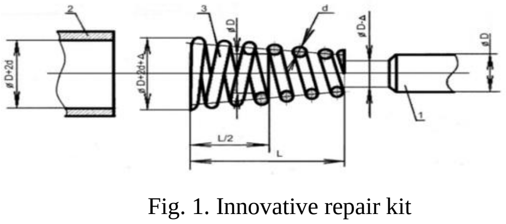

Fig. 1. Innovative repair kit

A mathematical model has been created that describes the process of changing the size [13, 14] of a conical movable spring insert in the sliding bearing of the cardan shaft crosspiece [15, 16, 18].

The method of calculating the conical spring liner is as follows.

The following assumptions are accepted:
- spring wire made of 65G steel;
- the absolute linear de formation of the spring liner f_x is equal to 1 mm;
- the length of the spring liner in the unloaded state H_x is equal to the length of the liner in the loaded state кH_0, since in this case it is not subjected to load;
- the angle at which the coils of the spring liner rise in its unloaded (free) state is set to $\alpha = 1{,}83^0$;
- the angle from which the axis of the screw bar begins to rise in an unloaded spring insert is denoted as $\alpha = \alpha_0$.

Due to the fact that the conical spring liner differs from the cylindrical one, new calculated values are used:

r_1 and r_2- the smallest and largest average radius of turns of a conical spring liner;

D_{0min}- the average diameter of the smallest coil of the conical spring liner;

D_{0max}- the average diameter of the largest coil of the conical spring liner.

Further calculation is performed for the spring liner, presented in the form of a rigid beam.

Bending stiffness of the beam:

$$B = Ea^4/12, \qquad (1)$$

where $E = 20 \cdot 10^4 МПа$ - modulus of elasticity of the first kind;

The rigidity of the beam during torsion:

$$C = \eta a^4 G = \eta a^4 E/2 \cdot (1+\mu), \qquad (2)$$

where μ - Poisson's ratio of the material of the parts;

Height (length) of the spring liner in the unloaded state:

$$l_0 = \pi D_0/\cos\alpha_0, \qquad (3)$$

Length of the working part of the spring liner:

$$H_0 = l_0 \sin\alpha_0, \qquad (4)$$

Axial force at which the conical spring liner is compressed to the limit:

$$P_{кп} = \frac{4\cos^2\alpha_0}{D_0^2} \cdot \left[C(\sin\alpha - \sin\alpha_0) - B\sin\alpha\left(1 - \frac{\cos\alpha_0}{\cos\alpha}\right)\right], \qquad (5)$$

Permissible bending moment:

$$M = M_0 = -\frac{PD_0(B-C)\sin 2\alpha_0}{4(B\sin^2\alpha_0 + C\cos^2\alpha_0)}, \qquad (6)$$

The average value of the torsion hook of the spring:

$$R = M/F, \qquad (7)$$

Return force generated when the conical spring is tensioned for a constant pitch bushing up to a specified height H_x:

$$F_x = \frac{f_x \cdot 2 \cdot C}{p \cdot n \cdot (r_2^2 + r_1^2) \cdot (r_2 + r_1)^2}, \qquad (8)$$

where

$f_x = H_0 - H_x$;

$x = 1{,}2{,}3$;

r_1, r_2– the average radius of the working part of the coils of the conical spring liner (r_1 - smallest and r_2 – largest);

Sediment under the action of the force P of the conical spring liner:

$$\lambda \approx \frac{0{,}25(H_0-H_m)}{(1-n)} \cdot \left(4 - 3\sqrt[3]{\frac{P_{н.п.}}{P}} - \frac{P}{P_{н.п.}} n^4\right), \quad (9)$$

where

$(r_1 - r_2)\ \langle i;\ i$ – number of working turns;

$P_{н.п.}$- he force at which the drawdown of the coils begins;

H_m– the height of the fully compressed conical spring liner:

$$H_m = \sqrt{(ia)^2 - (r_2 - r_1)^2}, \quad (10)$$

$$n = \frac{r_1}{r_2}, \quad (11)$$

, where *n* - the number of working turns of the spring.

The permissible size change of the conical movable spring bearing liner ΔD (radius $[f']$) в in its final form has the expression:

$$\Delta D(\Delta\lambda) = -\left[(P\Delta\lambda^3 \sin(\alpha_0)) \cdot \left(\frac{1}{2C} - \frac{\cos(2\alpha_0)}{4B\cos(\alpha_0)^2}\right)\right] - M\frac{\Delta\lambda^2}{2\cos(\alpha_0)} \cdot \left(\frac{\sin(\alpha_0)^2 2}{C} + \frac{\cos(2\alpha_0)}{B}\right) \quad (12)$$

$$[f'] = \frac{3\pi[P]R^3}{Ea^4}, \quad (13)$$

where $[P]$– permissible force to increase the radius of the spring ring;

$$[P] = \frac{[\sigma]a^2}{\left\{\frac{6R}{a}+1\right\}}, \quad (14)$$

where $[\sigma]$– permissible bending stress.

Based on the developed mathematical model the theoretical calculations and analysis of the driveshaft bearing can be conducted.

In order to determine which traditional landings are necessary for the confident operation of the spring liner, it is possible to apply VST methods (interchangeability, standardization and technical measurements).

We solve the problem for determining the elements of a smooth cylindrical joint.

Initial data:

- nominal size –*∅20*mm
- hole – *H5*
- shaft –*p4*

The amount of tolerances:

- hole –T_D=0,009mm
- shaft –T_d=0,006mm
- marginal deviations:

∅20H5:

EI=0;ES=EI+T_D=0,000+0,009=+0,009mm;

- Shaft:

∅20p4:ei=0,022;es=ei–T_d=0,022+0,006=0,028mm

Limit sizes:

Hole:

D_{max}= d_n+ ES= 20 + 0,009 = 20,009mm,

D_{min}= d_n+ EI = 20 + 0,000 = 20mm.

Shaft:

d_{max}=d_n+es=20+0,028=20,028mm,

d_{min}=d_n+ei=20+0,022=20,022mm.

Maximum clearances and tightnesses:

S_{max}=D_{max}-d_{min}=20,009 -20,022= - 0,013mm;

S_{min}=D_{min}-d_{max}=20-20,028= - 0,028mm;

N_{max}=d_{max}-D_{min}=20,028 – 20=0,013mm;

N_{min}=d_{min}-D_{max}=20,022-20,009=0,028mm.

Landing group:

- $\varnothing 20\frac{H5}{p4}$- tight fit.

Landing tolerance:

$T_П$=S_{max}-S_{min}=-0,013 -(-0,028) =0,015mm;

$T_П$=T_D+T_d=0,009+0,006=0,015mm.

Diagram of the tolerance fields of the connection$\varnothing 20\frac{H5}{p4}$ of the shaft and the conical spring plate figure

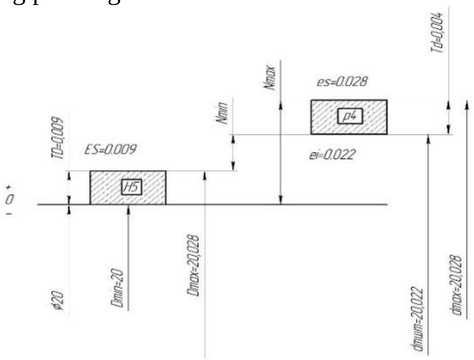

Fig. 2. Diagram of connection tolerance fields

Sketches of the connection assembly and its parts Figure 3.

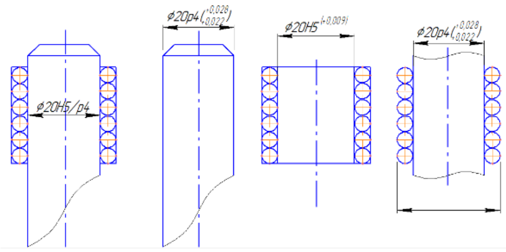

Fig. 3. Connection sketches

Based on the obtained calculations, it should be noted that the necessary precision of traditional fit requires the use of precise equipment and advanced tools. This clearly affects the calculation of the reasonableness of economic costs in the production of the spring insert and the parts cooperating with it. Additionally, exactly such equations and calculations cannot be applied to a plain bearing with a movable spring insert and requires a different approach. Therefore, it was proposed to make a conical spring insert and the remaining cooperating surfaces of the cylindrical part to ensure a tight fit on cylindrical surfaces [23, 24].

Table 1.

		Designation of the specified connection		*∅20 H5/p4*
The value of the connection elements		Nominal size, мм Nominal size, mm		20
		Gap (tension), mm	S_{max}	-0,013
			S_{min}	-0,028
		Landing tolerance, mm T_{Δ}		0,015
		Landing group		With tension
		Tolerance system		CO
Values of parts elements	Hole	Conditional designation		*∅20 H5*
		Allowance, mm TD		0,009
		The value of the main deviation, mm		0 (lower)
		Limit deviations, microns	Upper ES	+0,009
			Lower EI	0
		Limit sizes, mm	D_{max}, mm	20,009
			D_{min}, mm	20
		Conditional designation		*∅20 p4*
	Shaft	Allowance, mm Td		0,006
		The value of the main deviation, mm		0,022 (lower)
		Marginal deviations, µm	upper es	0,028
			lower ei	0,022
		limit sizes, mm	d_{max}, mm	20,028
			d_{min}, mm	20,022

3. PRACTICAL SIGNIFICANCE

Usually, crosspiece breakdowns occur due to the wear of needle bearings, their wear leads to jamming of the crosspiece and its further failure. In the crosspieces of cardan joints with a needle bearing, wear occurs called "false brinelling" (Figure 4). During oscillatory movements with small amplitudes Δα and large normal Rc loads, needle dents form on the working surfaces of the ring and the spike of the crosspiece, and further operation becomes impossible and dangerous (Figure 5).

a) b)

Fig. 4. The appearance of worn parts («false brining») of the bearing assembly of the crosspiece a) – the bearing cage; b) – the axle of the crosspiece

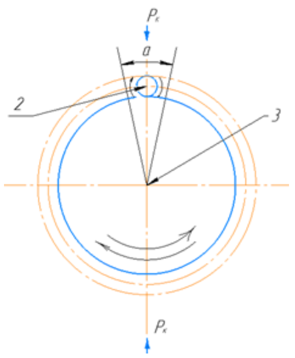

Fig. 5. Operation diagram of the needle bearing in the cardan shaft crosspiece

When repairing the crosspieces, the following technological requirements must be met:

- non-cylindrical spikes no more than 0.006 mm
- the deviation of the axes from the position in the same plane should be no more than 0.3 mm
- misalignment of the spikes no more than 0.01 mm
- non-pendicularity of the axes is not more than 0.2 mm
- roughness Ra of the "spike" surface is not worse than 0.32 microns according to Standart 2789-73
- CTT (Chemical-thermal treatment) of spikes – cementation h=1,4mm
- the hardness of the spikes is 61...67 HRC.

Worn-out crosspieces are repaired by installing a spring insert, if the brinelling of the crosspiece spike with a depth of depressions of no more than 0.5 mm, or surfacing under the AH-348A flux, if the depth of depressions exceeds 0.5 mm. You can use the UD-209 or A-547U installations. Next, the spikes are drilled, leaving an allowance for final processing of 0.2 mm per side. Then, high-frequency hardening of the spikes is performed. Next, the spikes are ground into the nominal size of the "spike" $Ø25^{-0,02}_{-0,04}$ and $Ø33,62_{-0,025}$mm, respectively, for parts 2201030 and 2205030 on circular or centerless grinding machines.

In terms of repairing the crossbar, it was proposed to replace the needle bearings with a spring insert; for this purpose, it is necessary to grind the surface of the crossbar spikes. This crossbar is equipped with a special movable insert in the form of a cylindrical spiral spring, which rotates only in one direction during oscillatory movements. This results in uniform wear and even distribution of the lubricant.

The proposed innovative repair kit, presented in Figure 6, was designed to improve the efficiency and effectiveness of the mechanism. These effects are achieved thanks to the use of a flexible intermediate element mechanism in the bearing as a movable insert in the form of a spiral-cylindrical spring. By adjusting the pressure force in the designed spring, it is possible to create a tight seal on the working surfaces. This eliminates oxidation processes and additionally causes microplastic deformation of the surface [19-22].

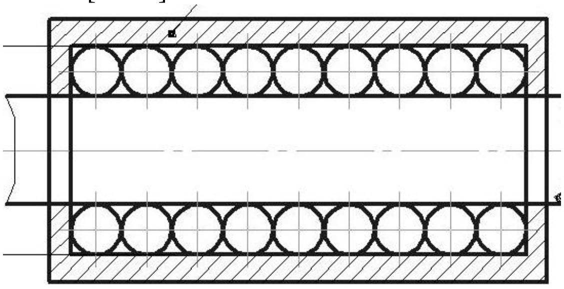

Fig. 6. Concept of bearing design with a movable spiral-cylindrical spring

In order to improve the stabilization of the operating mode and ensure uniformity of surface contact and, as a result, wear, the following modifications were introduced. During the cycle of reciprocating movement of the shaft or outer ring, during which the spring is twisted (compressed) or unwound (stretched), cyclic braking occurs as a result of contact on selected sections of the internal or external surfaces of the spring. The resulting braking effect generates forced rotation of the linear spring in only one direction, depending on the direction of spring winding. The effect of this mechanism is to improve the uniformity of wear. An additional effect is the constant change of direct contact surfaces on work surfaces, which further reduces the intensity of wear. The design also includes the possibility of adjusting the sealing level, e.g. to compensate for wear during repair. This is achieved by adding additional shims between one of the support washers and the end of the linear spring [25].

To achieve and maintain a wear-free regime when the above conditions are met, a variety of different methods and tools can be applied. These methods include the addition of metal-coating additives to the lubricant, the use of special non-abrasive processing methods (for example, finishing antifriction treatment), as well as the usage of metal-coating components materials.

It follows from the figure that the cardan shaft crosspiece with an innovative repair kit under load Figure 7 has a much better characteristic than the standard cardan shaft crosspiece Figure 8. It follows that the replacement of an innovative repair kit affects the characteristics of the cardan shaft crosspiece. The use of an innovative repair kit has a positive effect on the service life and reliability of the cardan shaft crosspiece. These are the effect of the spring sealing element to provide coupling with higher accuracy and durability.

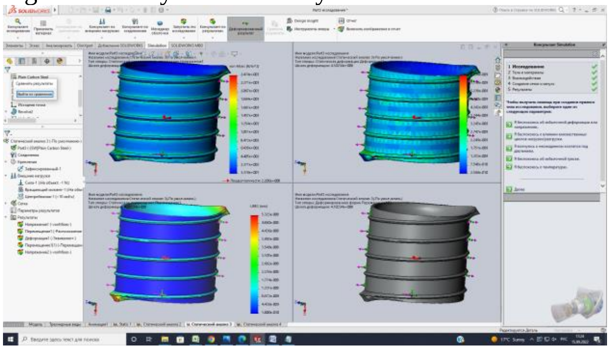

Fig. 7. Innovative repair kit under quality

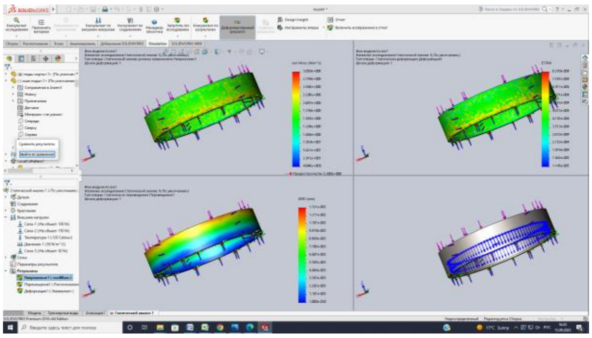

Fig. 8. Innovative repair kit under load

The diagnostic stand SIA-04 "ENGA" is designed for testing telescopic racks and shock absorbers of various types for passenger cars. The test is performed based on the method of harmonic oscillations and the construction of a working diagram of the shock absorber being tested (force-displacement coordinates) or speed characteristics (force-speed coordinates). The testing process is automated, controlled by a computer.

Fig. 9. Diagnostics of the speed characteristics of the front strut of the shock absorber with an innovative repair kit

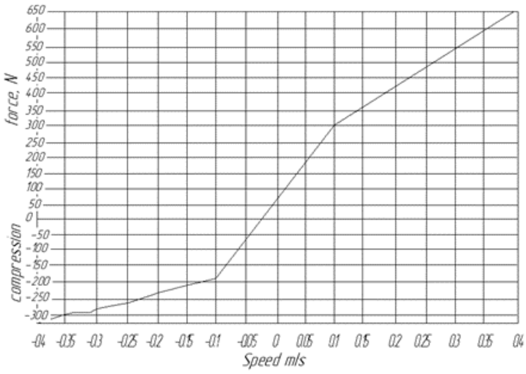

Fig. 10. High-speed characteristics of the front strut of the shock absorber with an innovative repair kit

Figure 10 shows a working diagram of the diagnostics of the speed characteristics of the front strut of the shock absorber with an innovative repair kit, the results showed within the standard values, but somewhat better than a standard shock absorber. Presumably, this is due to the better sealing of the piston ring, due to its innovative design. The use of a spring sealing piston ring will increase the service life of the piston-cylinder interface and will not adversely affect the characteristics of the shock absorber.

4. CONCLUSIONS

The concept of a sliding bearing designed for reciprocating motion using a conical spring liner has been created and presented. This design can be applied in various components of cars and other vehicles, such as suspension components (shock absorber), power train elements (cardan shaft joints), steering system components (differential), and others.

A method for calculating a conical spring liner for a sliding bearing has been developed, which can be used at enterprises when designing components and assemblies using innovative bearings.

Application of designed innovative repair kit can contributes to even 2-fold increase in the durability of elements operating under heavy loads in the reciprocating-rotational mode.

An additional economic benefit that may determine the implementation of the developed solution is the reduction of production and assembly costs of the developed repair kit. This is due to the lower required accuracy of the working surfaces of the cooperating parts, and therefore lower equipment requirements and shorter operational cycles during production.

Source of funding: *The source of funding for this article is the authors' own funds.*

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

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. Kushaliev DK. Operational characteristics of bearings with a spring insert based on new principles and effects. Gylym Zhane Bilim 2010; 1(18): 55-62.
2. Arystanov Z, Togizbayeva B, Karazhanov A, Alipbayev Z, Burkanova K. Investigation of the impact of operating conditions on the service life of locomotive wheelset tyres. Journal of the Balkan Tribological Association 2022; 28(6), 882–896.
3. 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.
4. Kharchenko Y, Dragun Ł. Mathematical modeling of unsteady processes in electromechanical system of ring-ball mill. Diagnostyka 2017; 18(1): 25–35.
5. Yang BS, Lee YH, Choi BK, Kim HJ. Optimum Design of Short Journal Bearings by Artificial Life Algorithm. Tribology International 2001; 34: 427–435.
6. Hevko B, Lootsiv I, Hevko I, Komar R, Dubynyak T. Flexible - safety clutches: construction, calculation, study (in Ukrainian). Publishing FOP Paljanyca V.A., Ternopil, 2019.
7. Orobey V, Nemchuk O, Lymarenko O, Piterska V, Sherstiuk O, Lehetska I. Diagnostics of stabilization modes of shape strand ropes. Diagnostyka 2022; 23(4): 1–9. https://doi.org/10.29354/diag/156385.
8. Chiker Y, Bachene M, Attaf B, Hafaifa A, Guemana M. Uncertainty influence of nanofiller dispersibilities on the free vibration behavior of multi-layered functionally graded carbon nanotube-reinforced composite laminated plates. Acta Mechanica 2023; 234(4): 1687–711. https://doi.org/10.1007/s00707-022-03438-6.
9. Tadayoshi S. Nonlinear Vibration of Saturated Water Journal Bearing and Bifurcation Analysis. Journal of Vibration and Acoustics 2019; 141(021016). https://doi.org/10.1115/1.4042041.
10. Shabanian M, Montazeri M. A neuro-fuzzy online fault detection and diagnosis algorithm for nonlinear and dynamic systems. International Journal of Control, Automation and Systems 2011; 9(4): 665–70. https://doi.org/10.1007/s12555-011-0407-9.
11. Roig Greidanus MD, Heldwein ML. Model-Based Control Strategy to Reduce the Fault Current of a Gas Turbine Synchronous Generator under Short-Circuit in Isolated Networks. Electric Power Systems Research 2022; 204: 107687. https://doi.org/10.1016/j.epsr.2021.107687.
12. Lyantsev OD, Breikin TV, Kulikov GG, Arkov VY. Optimal multi-variable control of gas turbine engines. International Journal of Systems Science 2004; 35(2): 79–86. https://doi.org/10.1080/00207720310001657036.
13. Bulut G, Parlar Z. Dynamic stability of a shaft system connected through a Hooke's joint. Mechanism and

Machine Theory 2011; 46(11): 1689–95. https://doi.org/10.1016/j.mechmachtheory.2011.06.012.

14. 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): 540–51. https://doi.org/10.1177/1077546319889846.
15. Vesali F, Rezvani MA, Kashfi M. Dynamics of universal joints, its failures and some propositions for practically improving its performance and life expectancy. Journal of Mechanical Science and Technology 2012; 26(8): 2439–49. https://doi.org/10.1007/s12206-012-0622-1.
16. Rahbar-kelishami A, Abdollah-zadeh A, Hadavi MM, Banerji A, Alpas A, Gerlich AP. Effects of friction stir processing on wear properties of WC–12%Co sprayed on 52100 steel. Materials & Design 2015; 86: 98–104. https://doi.org/10.1016/j.matdes.2015.06.132.
17. Strecker W. Failure Analysis for Plain Bearings. Machinery Lubrication magazine. July-August. 2004.
18. Dascălu A, Istrate B, Munteanu C, Cîrlan CP, Paleu V. Morphological and tribological studies of thermal plasma jet deposited coatings used in cardan joints. IOP Conference Series: Materials Science and Engineering 2020; 997(1): 012022. https://doi.org/10.1088/1757-899X/997/1/012022.
19. Vashishtha N, Khatirkar RK, Sapate SG. Tribological behaviour of HVOF sprayed WC-12Co, WC-10Co-4Cr and Cr3C2−25NiCr coatings. Tribology International 2017; 105: 55–68. https://doi.org/10.1016/j.triboint.2016.09.025.
20. Longo FN. Coating Processing. Handbook of Thermal Spray Technology; Davis, JR, Ed; ASM International: Materials Park, OH, USA, 2004; 108–119.
21. Berry J. Oil Whirl and Whip Instabilities within Journal Bearings. Machinery Lubrication magazine. May-June. 2005.
22. Kushaliev DK. Modeling of a sliding bearing with a movable spring insert for units of transport equipment and technological equipment. Kirov 2012; 28-30.
23. Kushaliev DK. Theoretical substantiation of the use of a conical spring insert instead of a cylindrical one for a reciprocating-rotary bearing in shock absorber silent blocks. SSTU 2013; 1(73): 231-235.
24. Kushaliev D, Korabay R. Development of a CPG repair kit with the application of a new tribo joint as a type of functional tuning. Bulletin of L.N. Gumilyov ENU. Technical Science and Technology Series. 2023; 1(142): 67-73. https://doi.org/10.32523/2616-7263-2023-142-1-67-73.
25. Chi SH, Chung YL. Mechanical behavior of functionally graded material plates under transverse load—Part I: Analysis. International Journal of Solids and Structures 2006; 43(13): 3657–3674. https://doi.org/10.1016/j.ijsolstr.2005.04.011.

KUSHALIYEV Dauren
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: Zkaty777@gmail.com

ZABIYEVA Aliya
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

Akzharkyn BALGYNOVA,
currently works an assistant professor at the Department of Oil and Gas Business of the K. Zhubanov Aktobe Regional University. Received a technical education (mechanical engineering) at the West Kazakhstan Agricultural Institute and a PhD degree in technology and agricultural mechanization at the Atyrau Institute of Oil and Gas. Has 30 years of teaching and research experience. Authored over 50 publications, including: in journals recommended by the Higher Attestation Commission of the Republic of Kazakhstan, in Kazakh and international journals, in scientific conferences, two copyright certificates of the Republic of Kazakhstan, one monograph. Research interests: ensuring the operability of various units, components and parts of agricultural and petroleum equipment, technological processes in the processing of oil waste using high-tech equipment to produce high-quality products.
e-mail: balgynova.am@gmail.com

Rafał BURDZIK is a professor in the Faculty of Transport and Aviation Engineering at Silesian University of Technology, Poland and visiting lecturer at many European Universities with more than twenty years of transport research experience. He is an author or co-author of books and more than 450 scientific papers, and an editorial board member for several high level scientific journals and active member of numerous scientific associations, editorial boards and committees. He manages numerous innovative and implementation research

projects in partnership with industrial entities. He is a well-recognized international expert in transport, mechanical engineering, vibroacoustic, machine diagnostic, transport safety and environmental issues.
Contact: rafal.burdzik@polsl.pl

ALIPBAYEV Zhasulan, is currently working as an acting associate professor at the department of “Transport, transport equipment and technology”, candidate of technical sciences,. Authored over 40 publications, including: in journals recommended by the Higher Attestation Commission of the Republic of Kazakhstan, in Kazakh and international journals, in scientific conferences.
e-mail: zasulanalipbaev40@gmail.com