ABSTRACT AND REFERENCES

APPLIED MECHANICS

DOI: 10.15587/1729-4061.2019.168145

DEVISING AN ENGINEERING PROCEDURE FOR CALCULATING THE DUCTILITY OF A ROLLER BEARING UNDER A NO-CENTRAL RADIAL LOAD (p. 6–10)

Anatoly Gaydamaka
National Technical University
«Kharkiv Polytechnic Institute», Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-6952-4086

Gennady Kulik
National Technical University
«Kharkiv Polytechnic Institute», Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0001-8746-8842

Viktor Frantsuzov
National Technical University
«Kharkiv Polytechnic Institute», Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-2285-2568

Iryna Hrechka
National Technical University
«Kharkiv Polytechnic Institute», Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0003-4907-9170

Serhii Khovanskyi
Sumy State University, Sumy, Ukraine
ORCID: http://orcid.org/0000-0003-2435-7787

Andrii Rogovyi
Kharkiv National Automobile and
Highway University, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-6057-4845

Maksym Svynarenko
Kharkiv National University of Civil Engineering
and Architecture, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0001-9134-2759

Maria Maksimova
National University of Civil Defence
of Ukraine, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0001-6287-2750

Nadiia Paraniak
Lviv Polytechnic National University, Lviv, Ukraine
ORCID: http://orcid.org/0000-0002-6673-4002

Known theoretical approaches to calculating the ductility of rolling bearings include rather complicated analytical dependences and require cumbersome computation. That makes it a relevant task to undertake a research aimed at the development of an engineering approach to the calculation of radial ductility of bearings.

The current study proposes an engineering method for determining radial ductility using cylindrical roller bearings as an example. It accounts for the radial gap, contact deformation of parts, the deformations of bending and misalignment of rings for cases when a bearing is exposed to the action of a central radial load and a radial load with eccentricity. The adopted simplified linear calculation model for determining the angle of rings misalignment is valid for small angles when contact is maintained over the entire length of the roller. Computation of radial ductility of roller bearings under a no-central radial load is based on determining the sum of variable elastic deformations in a contact between rings and the most loaded roller. The values for elastic deformations are determined from known formulae for solving the contact problem in elasticity theory taking into consideration a mismatch between the geometric centers of outer and inner rings.

Adequacy of the proposed engineering procedure has been confirmed by results from calculating the specific ductility of the cylindrical roller bearing 2211 with a central radial load. By using the proposed methodology, we have derived values for specific ductility that are 3...4 % lower compared to similar results obtained from a known procedure. By using the cylindrical roller bearing 42726 as an example, we have investigated structural parameters considering a no-central radial load. A decrease in the bearing 42726 ductility with an increase in the number of rollers and rigidity of the outer ring has been shown, as well as with a decrease in the eccentricity of a radial load.

The ductility of rolling bearings must be known when constructing dynamic models of certain machines: machine tool spindles, shaft-gears at large-size reducers, crane structures. Therefore, the proposed engineering procedure for determining the ductility of roller bearings at small angles of rings misalignment could be applied in the practice of designing machines and mechanisms for which the elastic characteristics of all their components are important.

Keywords: engineering calculation procedure, roller bearings ductility, contact deformations, no-central radial load, misalignment of rings.

References

1. Guay, P., Frikha, A. (2015). Ball Bearing Stiffness. A New Approach Offering Analytical Expressions. Proc. «16th European Space Mechanisms and Tribology Symposium 2015». Bilbao.
2. Chernyshenko, A. V., Pavlov, A. A. (2009). K voprosu opredeleniya zhestkosti podshipnikov kacheniya v buksah kranovyh koles. Eastern-European Journal of Enterprise Technologies, 1 (5 (37)), 47–50. Available at: http://journals.uran.ua/eejet/article/view/3141/2944
3. Erem'yants, V. (2011). Vliyanie tipa podshipnika kacheniya na privedennyy koeffitsient ego zhestkosti. Vestnik KRSU, 11 (11), 94–100.
4. Nahatakyan, F. G. (2015). Podatlivost' rolikovyh podshipnikov. Vestnik mashinostroeniya, 2, 19–21.
5. Tong, V., Hong, S. (2016). Study on Stiffness of Cylindrical Roller Bearings Under Combined Radial and Moment Loads. Proceedings of 39th IASTEM International Conference. Hanoi, 29–32.
6. Fujiwara, H., Kawase, T., Kobayashi, T., Yamauchi, K. (2009). Optimized Logarithmic Roller Crowning Design of Cylindrical Roller Bearings and Its Experimental Demonstration. ASME/STLE 2009 International Joint Tribology Conference. doi: https://doi.org/10.1115/ijtc2009-15032
7. Chen, G., Wang, H. (2016). Contact stress and radial stiffness of a cylindrical roller bearing with corrected roller generator. Transactions of the Canadian Society for Mechanical

Engineering, 40 (5), 725–738. doi: https://doi.org/10.1139/tcsme-2016-0059

8. Lazarz, B., Petun, G., Bucki, S. (2008). Application of the Finite-Element Method for Determining the Stiffness of Rolling Bearings. Transport problems, 3, 33–40.
9. Zhang, Y., Sun, G., Lim, T., Xie, L. (2015). A fast and reliable numerical method for analyzing loaded rolling element bearing displacements and stiffness. Journal of Vibroengineering, 17 (2), 620–642.
10. Larizza, F., Moazen-Ahmadi, A., Howard, C. Q., Grainger, S. (2018). The importance of bearing stiffness and load when estimating the size of a defect in a rolling element bearing. Structural Health Monitoring, 147592171880880. doi: https://doi.org/10.1177/1475921718808805
11. Ponomarev, S. D. et. al. (1958). Raschety na prochnost' v mashinostroenii. Moscow, 974.
12. Gaydamaka, A., Klitnoy, V., Muzikin, Y., Tat'kov, V., Hrechka, I. (2018). Construction of a model for the distribution of radial load among the bearing's rolling bodies. Eastern-European Journal of Enterprise Technologies, 6 (7 (96)), 39–44. doi: https://doi.org/10.15587/1729-4061.2018.149964
13. Perel', L. Ya. (1983). Podshipniki kacheniya: raschet, proektirovanie i obsluzhivanie opor. Moscow, 543.
14. Tsyurenko, V. N., Petrov, V. A. (1982). Nadezhnost' rolikovyh podshipnikov v buksah vagonov. Moscow, 96.

DOI: 10.15587/1729-4061.2019.169631

CALCULATION OF STRESS CONCENTRATIONS IN ORTHOTROPIC CYLINDRICAL SHELLS WITH HOLES ON THE BASIS OF A VARIATIONAL METHOD (p. 11–17)

Valentin Salo
National Academy of National Guard of Ukraine,
Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0003-2533-0949

Valeriia Rakivnenko
National Academy of National Guard of Ukraine,
Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-6136-6191

Vladimir Nechiporenko
National Academy of National Guard of Ukraine,
Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-4727-7344

Aleksandr Kirichenko
National Academy of National Guard of Ukraine,
Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0001-9136-7593

Serhii Horielyshev
Moscow Aviation Institute
(National Research University), Moscow, Russia
ORCID: http://orcid.org/0000-0003-1318-7823

Dmytro Onopreichuk
Ukrainian State University of Railway Transport,
Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-6314-3936

Volodymyr Stefanov
Ukrainian State University of Railway Transport,
Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-7947-2718

A variational numerical-analytical method (called the RVR method) is suggested for calculating the strength and stiffness of statically loaded non-thin orthotropic shell structures weakened by holes (stress concentrators) of arbitrary shapes and sizes. The theoretically substantiated new method is based on the Reissner variational principle and the method of I. N. Vekua (the method of decomposing the desired functions into the Fourier series of the orthogonal Legendre polynomials with respect to the coordinate along the constant shell thickness). In this case, the use in the proposed RVR method of the general equations of three-dimensional problems of the linear theory of elasticity makes it possible to determine the total stress-strained state of an elastic shell (in particular, a plate) with holes. At the same time, using the R-functions, at the analytical level, the geometric information of boundary-value problems for multiply connected domains is taken into account and solutions structures are constructed that exactly satisfy different variants of boundary conditions. The use of a software-implemented algorithm for the two-sided integral assessment of the accuracy of approximate solutions in the study of mixed variational problems helps automate the search for such a number of approximations in which the process of convergence of solutions becomes stable.

For orthotropic and isotropic materials, the possibilities of the RVR method are shown in numerical examples of solving the corresponding boundary value problems of calculating the stress concentration in a cylindrical shell with an elliptical or rectangular hole under axial load. The results of the performed tests are discussed, and the features characteristic of the new method prove that it can be effectively used in the design of critical lamellar and shell elements of structures in various fields of modern technology.

Keywords: orthotropic shell with holes, stress concentration, Reissner principle, R-functions theory.

References

1. Rezaeepazhand, J., Jafari, M. (2010). Stress concentration in metallic plates with special shaped cutout. International Journal of Mechanical Sciences, 52 (1), 96–102. doi: https://doi.org/10.1016/j.ijmecsci.2009.10.013
2. Guz', A. N., Chernyshenko, I. S., Chekhov, Val. N., Chekhov, Vik. N., Shnerenko, K. I. (1980). Teoriya tonkih obolochek, oslablennyh otverstiyami. Vol. 1. Metody rascheta obolochek. Kyiv: Naukova dumka, 636.
3. Washizu, K. (1982). Variational methods in elasticity and plasticity. New York, 542.
4. Klochkov, Y. V., Nikolaev, A. P., Sobolevskaya, T. A., Klochkov, M. Y. (2018). Comparative analysis of efficiency of use of finite elements of different dimensionality in the analysis of the stress-strain state of thin shells. Structural Mechanics of Engineering Constructions and Buildings, 14 (6), 459–466. doi: https://doi.org/10.22363/1815-5235-2018-14-6-459-466
5. Li, J., Shi, Z., Liu, L. (2019). A scaled boundary finite element method for static and dynamic analyses of cylindrical shells. Engineering Analysis with Boundary Elements, 98, 217–231. doi: https://doi.org/10.1016/j.enganabound.2018.10.024
6. Ádány, S. (2016). Shell element for constrained finite element analysis of thin-walled structural members. Thin-Walled Structures, 105, 135–146. doi: https://doi.org/10.1016/j.tws.2016.04.012
7. Ádány, S. (2017). Constrained shell finite element method for thin-walled members with holes. Thin-Walled Structures, 121, 41–56. doi: https://doi.org/10.1016/j.tws.2017.09.021

8. Salo, V. A. (2003). Kraevye zadachi statiki obolochek s otverstiyami. Kharkiv: NTU «KhPI», 216.
9. Reissner, E. (1950). On a Variational Theorem in Elasticity. Journal of Mathematics and Physics, 29 (1-4), 90–95. doi: https://doi.org/10.1002/sapm195029190
10. Pramod, A. L. N., Natarajan, S., Ferreira, A. J. M., Carrera, E., Cinefra, M. (2017). Static and free vibration analysis of cross-ply laminated plates using the Reissner-mixed variational theorem and the cell based smoothed finite element method. European Journal of Mechanics – A/Solids, 62, 14–21. doi: https://doi.org/10.1016/j.euromechsol.2016.10.006
11. Faghidian, S. A. (2018). Reissner stationary variational principle for nonlocal strain gradient theory of elasticity. European Journal of Mechanics - A/Solids, 70, 115–126. doi: https://doi.org/10.1016/j.euromechsol.2018.02.009
12. Vekua, I. N. (1965). Teoriya tonkih pologih obolochek peremennoy tolschiny. Vol. 30. Tbilisi, 3–103.
13. Timoshenko, S., Woinowsky-Krieger, S. (1987). Theory of Plates and Shells. New York: McGraw-Hill Book Company, 580.
14. Salo, V. A., Nechiporenko, V. M. (2017). Research of durability of the elastic cylindrical structure affected by the local loading. Zbirnyk naukovykh prats Natsionalnoi akademiyi Natsionalnoi hvardiyi Ukrainy, 2, 76–82.
15. Salo, V. A., Litovchenko, P. I., Chizhikov, I. V. (2011). Napryazhenno-deformirovannoe sostoyanie uprugoy tsilindricheskoy paneli s otverstiem. Voprosy proektirovaniya i proizvodstva konstruktsiy letatel'nyh apparatov, 1, 63–70.
16. Salo, V. A. (2004). O kontsentratsii napryazheniy okolo otverstiya v uprugoy sfericheskoy obolochke. Voprosy proektirovaniya i proizvodstva konstruktsiy letatel'nyh apparatov, 2, 66–72.
17. Salo, V. A. (2000). Dokazatel'stvo dostatochnogo priznaka skhodimosti metoda Rittsa dlya smeshannogo variatsionnogo printsipa Reyssnera. Vestnik Har'kov. gos. politekh. un-ta, 95, 70–75.
18. Awrejcewicz, J., Kurpa, L., Shmatko, T. (2015). Investigating geometrically nonlinear vibrations of laminated shallow shells with layers of variable thickness via the R-functions theory. Composite Structures, 125, 575–585. doi: https://doi.org/10.1016/j.compstruct.2015.02.054
19. Nechyporenko, V. M., Salo, V. A., Litovchenko, P. I., Kovbaska, B. V., Verkhorubov, D. O. (2016). Vykorystannia teoriyi R-funktsiy dlia stvorennia ratsionalnykh posadok z natiahom. Zbirnyk naukovykh prats Natsionalnoi akademiyi Natsionalnoi hvardiyi Ukrainy, 2, 72–76.
20. Rodionova, V. A., Titaev, B. F., Chernyh, K. F. (1996). Prikladnaya teoriya anizotropnyh plastin i obolochek. Sankt-Peterburg: SpbGU, 278.
21. Rodionova, V. A. (1983). Teoriya tonkih anizotropnyh obolochek s uchetom poperechnyh sdvigov i obzhatiya. Leningrad: LGU, 116.
22. Salo, V. A. (2003). O dvustoronney otsenke tochnosti priblizhennyh resheniy zadach teorii obolochek, poluchennyh metodom Rittsa dlya neekstremal'nogo funktsionala Reyssnera. Dopovidi NAN Ukrainy, 1, 53–57.
23. Tennyson, R. S., Roberts, D. K., Zimcik, D. (1968). Analysis of the stress distribution around unreinforced cutouts in circular cylindrical shells under axial compressions. NRC, NASA, Annyal Progress Report, UTIAS.
24. Zirka, A. I., Chernopiskiy, D. I. (2001). Eksperimental'nye issledovaniya kontsentratsii napryazheniy v tolstyh tsilindricheskih obolochkah s pryamougol'nymi otverstiyami pri osevom szhatii. Prikladnaya mekhanika, 5, 133–135.

DOI: 10.15587/1729-4061.2019.166329

DETERMINING THE DYNAMIC LOADING ON AN OPEN-TOP WAGON WITH A TWO-PIPE GIRDER BEAM (p. 18–25)

Oleksij Fomin
State University of Infrastructure
and Technology, Kyiv, Ukraine
ORCID: http://orcid.org/0000-0003-2387-9946

Alyona Lovska
Ukrainian State University of Railway Transport,
Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-8604-1764

Olena Daki
Danube Faculty of Maritime and
River Transport of State University of Infrastructure
and Technology, Izmail, Ukraine
ORCID: http://orcid.org/0000-0003-3932-462X

Volodymyr Bohomia
Danube Faculty of Maritime and
River Transport of State University of Infrastructure
and Technology, Izmail, Ukraine
ORCID: http://orcid.org/0000-0003-4403-3130

Olena Tymoshchuk
Kyiv Institute of Marine Transport of the State University
of Infrastructure and Technology, Kyiv, Ukraine
ORCID: http://orcid.org/0000-0003-3684-6182

Viktor Tkachenko
State University of Infrastructure and Technology,
Kyiv, Ukraine
ORCID: http://orcid.org/0000-0002-5513-2436

To ensure the structural strength of open-top wagons, it has been proposed to introduce the concept of a traction device that could be implemented in open-top wagons with bearing elements made of round pipes. Feature of the concept is that the console parts of the girder beam are filled with a viscous substance with damping and anticorrosive properties. To convert the shock kinetic energy into the dissipation energy, the concept design includes a piston with two throttle valves (inlet and outlet).

In order to determine the dynamic load on the bearing structure of an open-top wagon equipped with a concept design of the traction device, mathematical modeling was performed. A mathematical model of the open-top wagon dynamic load during shunting collision has been constructed. It was considered that the frame of an open-top wagon is exposed to a longitudinal load of 3.5 MN. Differential equations were solved in line with a Runge-Kutta method in the programming environment Mathcad. It was established that the maximum magnitude of acceleration that acts on an open-top wagon, taking the improvement into consideration, is about 30 m/s^2. The proposed technical solutions make it possible to reduce the magnitude of dynamic load on a open-top wagon's bearing structure at shunting collision by 25 %.

The software CosmosWorks was used to perform computer simulation of the dynamic load on an open-top wagon. The finite element method was applied as a calculation technique. In this case, maximum accelerations amounted to about 37 m/s^2 and were concentrated at the console parts of a girder beam.

Adequacy of the developed models of dynamic loading on an open-top wagon's bearing structure was tested against the Fisher criterion (F-criterion). The optimal number of measurements was defined based on the Student-Gorset criterion. The results from calculation have demonstrated that the hypothesis of adequacy is not rejected.

This study will contribute to a decrease in the dynamic load on the bearing structures of open-top wagons in operation, as well as bring down the cost of unscheduled repairs. The current research enables the compilation of guidelines on designing innovative rolling stock with improved technical and economic indicators.

Keywords: open-top wagon, bearing structure, accelerations, dynamic loading, traction device, shunting collision.

References

1. GOST 22235-2010. Vagony gruzovye magistral'nyh zheleznyh dorog kolei 1520 mm. Obschie trebovaniya po obespecheniyu sohrannosti pri proizvodstve pogruzochno-razgruzochnyh i manevrovyh rabot (2011). Moscow, 24.
2. Senderov, G. K., Losev, P. R., Drugal', S. A. (1984). Sohrannost' vagonov pri pogruzochno-razgruzochnyh i manevrovyh rabotah. Moscow, 158.
3. Tretiakov, A. V., Tretiakov, O. A., Zimakova, M. V., Petrov, A. A. (2017). Experimental evaluation of shock spectrum response of rolling stock. Science and Transport Progress. Bulletin of Dnipropetrovsk National University of Railway Transport, 3 (69), 147–159. doi: https://doi.org/10.15802/stp2017/103898
4. Fomin, O. V., Lovska, A. O., Plakhtii, O. A., Nerubatskyi, V. P. (2017). The influence of implementation of circular pipes in load-bearing structures of bodies of freight cars on their physico-mechanical properties. Scientific Bulletin of National Mining University, 6, 89–96.
5. Fomin, O., Kulbovsky, I., Sorochinska, E., Sapronova, S., Bambura, O. (2017). Experimental confirmation of the theory of implementation of the coupled design of center girder of the hopper wagons for iron ore pellets. Eastern-European Journal of Enterprise Technologies, 5 (1 (89)), 11–18. doi: https://doi.org/10.15587/1729-4061.2017.109588
6. Myamlin, S., Lunys, O., Neduzha, L., Kyryl'chuk, O. (2017). Mathematical Modeling of Dynamic Loading of Cassette Bearings for Freight Cars. Proc. of 21st Intern. Scientific Conf. «Transport Means. 2017», 973–976.
7. Lovska, A. (2015). Peculiarities of computer modeling of strength of body bearing construction of gondola car during transportation by ferry-bridge. Metallurgical and mining industry, 1, 49–54.
8. Gevorkyan, E., Lavrynenko, S., Rucki, M., Siemiatkowski, Z., Kislitsa, M. (2017). Ceramic cutting tools out of nanostructured refractory compounds. International Journal of Refractory Metals and Hard Materials, 68, 142–144. doi: https://doi.org/10.1016/j.ijrmhm.2017.07.006
9. Boronenko, Yu. P. (2013). Car-builders' strategic tasks in development of heavy-weight rail traffic. Transport Rossiyskoy Federacii, 5 (48), 68–73.
10. Innovacionniy podvizhnoy sostav proizvodstva «Uralvagonzavoda» dlya zheleznyh dorog «prostranstva 1520 mm» (2010). Transport Rossiyskoy Federacii, 3 (28), 20–21.
11. Kebal, Y., Shatov, V., Tokotyev, A., Murashova, N. (2017). Improving the design of hopper wagons for transporting grain. Zbirnyk naukovykh prats DETUT. Seriya «Transportni systemy i tekhnolohiyi», 30, 113–122.
12. Okorokov, A., Fomin, O., Lovska, A., Vernigora, R., Zhuravel, I., Fomin, V. (2018). Research into a possibility to prolong the time of operation of universal open top wagon bodies that have exhausted their standard resource. Eastern-European Journal of Enterprise Technologies, 3 (7 (93)), 20–26. doi: https://doi.org/10.15587/1729-4061.2018.131309
13. Sapronova, S., Tkachenko, V., Fomin, O., Hatchenko, V., Maliuk, S. (2017). Research on the safety factor against derailment of railway vehicles. Eastern-European Journal of Enterprise Technologies, 6 (7 (90)), 19–25. doi: https://doi.org/10.15587/1729-4061.2017.116194
14. Bogomaz, G. I., Mekhov, D. D., Pilipchenko, O. P., Chernomashenceva, Yu. G. (1992). Nagruzhennost' konteynerov-cistern, raspolozhennyh na zheleznodorozhnoy platforme, pri udarah v avtoscepku. Zb. nauk. prats "Dynamika ta keruvannia rukhom mekhanichnykh system". Kyiv: ANU, Instytut tekhnichnoi mekhaniky, 87–95.
15. Domin, Yu. V., Cherniak, H. Yu. (2003). Osnovy dynamiky vahoniv. Kyiv: KUETT, 269.
16. Lukin, V. V., Shadur, L. A., Koturanov, V. I., Hohlov, A. A., Anisimov, P. S. (2000). Konstruirovanie i raschet vagonov. Moscow, 731.
17. DSTU 7598:2014. Vahony vantazhni. Zahalni vymohy do rozrakhunkiv ta proektuvannia novykh i modernizovanykh vahoniv koliyi 1520 mm (nesamokhidnykh) (2015). Kyiv, 162.
18. GOST 33211-2014. Vagony gruzovye. Trebovaniya k prochnosti i dinamicheskim kachestvam (2016). Moscow, 54.
19. EN 12663-2. Railway applications – structural requirements of railway vehicle bodies – Part 2: Freight wagons (2010). BSI, 54. doi: https://doi.org/10.3403/30152552u
20. Kobzar', A. I. (2006). Prikladnaya matematicheskaya statistika. Moscow, 816.
21. Ivchenko, G. I., Medvedev, Yu. I. (2014). Matematicheskaya statistika. Moscow, 352.
22. Rudenko, V. M. (2012). Matematychna statystyka. Kyiv, 304.

DOI: 10.15587/1729-4061.2019.168260

A STUDY OF THE EFFECTS OF CLIMATIC TEMPERATURE CHANGES ON THE CORRUGATED STRUCTURE (p. 26–35)

Bohdan Gera
Dnipro National University of Railway Transport
named after Academician V. Lazaryan,
Dnipro, Ukraine
ORCID: http://orcid.org/0000-0002-5413-5176

Vitalii Kovalchuk
Dnipro National University of Railway Transport
named after Academician V. Lazaryan,
Dnipro, Ukraine
ORCID: http://orcid.org/0000-0003-4350-1756

The study provides the results of experimental tests on temperature distribution throughout the surface of a corrugated metal sheet.

Mathematical models are proposed for calculating the thermal conductivity and the thermal stress state of a fragment of the corrugated metal frame of a transportation facility whose lateral surfaces are heated to different temperatures. It is assumed that the temperature depends on two spatial variables. As a possible criterion for choosing the desired function of temperature distribution throughout the construction, it is assumed that the functional defined by a set of admissible functions is minimized in the form of an integral throughout the region of the body from the expression given by the production of entropy.

In the study of the temperature field, the differential equation of thermal conductivity is used, and the stress-strain state is measured by the equation of the theory of thermal elasticity. To solve the differential heat equation, the method of finite differences is used, and for the solution of the equations of the theory of thermal elasticity, the finite element method is applied.

It has been established that the temperature is distributed unevenly throughout the corrugated metal sheet. There is a temperature difference between the lower and upper surfaces of the corrugated metal sheet. The temperature difference between the bottom and top sides of the sheet is +7.1 °C at the highest atmospheric temperatures and –5.5 °C at the lowest atmospheric temperatures.

It has been determined that the magnitude of the stresses that appear on corrugated metal sheets due to the atmospheric temperature difference is up to 25 % of the permissible stress. Therefore, when designing corrugated metal structures, it is necessary to calculate the effect of climatic temperature changes.

The obtained data of the thermal stress state of corrugated metal structures are important for design enterprises. It is because taking into account the action of the temperature field on the stress state of the structure as a whole at the design stage helps select materials to reduce the temperature stresses that have a direct influence on the development of corrosion damage to the metal of the pipe.

Keywords: corrugated metal frame, temperature distribution, temperature field, thermal stress state.

References

1. Kovalchuk, V. (2014). Study of temperature field and stress state of metal convoluted pipes. Resursoekonomni materialy, konstruktsiyi, budivli ta sporudy, 29, 186–192.
2. Machelski, Cz. (2008). Modelowanie mostowych konstrukcji gruntowo-powlokowych. Dolnoslaskie Wydawnictwo Edukacyjne, 208.
3. Machelski, Cz. (2010). Kinematic method for determining influence function of internal forces in the steel shell of soil-steel bridge. Studia Geotechnica et Mechanica, XXXII (3), 27–40.
4. Pettersson, L., Leander, J., Hansing, L. (2002). Fatigue design of soil steel composite bridges. Archives of institute of civil engineering, 12, 237–242.
5. Luchko, Y. Y., Kovalchuk, V. V. (2012). Vymiriuvannia napruzheno-deformovanoho stanu konstruktsiy mostiv pry zminnykh temperaturakh i navantazhenniakh. Lviv: Kameniar, 235.
6. Mangerig, I. (1986). Klimatische Temperaturbeanspruchung von Stahl- und Stahlverbundbrucken. Inst. für Konstruktiven Ingenieurbau, Ruhr-Univ., 143.
7. Luchko, J., Hnativ, Y., Kovalchuk, V. (2013). Method of calculation of temperature field and deflected mode of Bridge structures in software environment NX Nastran. Theoretical Fuundations of Civil Engineering, 21, 107–114.
8. Dilger, W. H., Ghali, A., Chan, M., Cheung, M. S., Maes, M. A. (1983). Temperature Stresses in Composite Box Girder Bridges. Journal of Structural Engineering, 109 (6), 1460–1478. doi: https://doi.org/10.1061/(asce)0733-9445(1983)109:6(1460)
9. Belyaev, V. S., Sandgarten, M. L. (2009). Metodicheskie osnovy prakticheskih raschetov metallicheskih gofrirovannyh konstruktsiy. Stroymetall, 1, 17–19.
10. Priestley, M. J. N., Buckle, I. G. (1978). Ambient Thermal Response of Concrete Bridges. Bridge Seminar. Vol. 2.
11. DBN V.2.3-14: 2006. Sporudi transportu. Mosti ta trubi. Pravila proektuvannya (2006). Kyiv, 359.
12. AASHTO Guide specifications: Thermal effects in concrete bridge superstructures (1989). Washington, DC: American Association of State Highway and Transportation Officials.
13. Rekomendatsii po raschetu temperaturnyh i usadochnyh vozdeystviy na proletnye stroeniya mostov (1988). Odobreny Glavtransproektom. Moscow, 17.
14. EN_1991-1-5-2009. Evrokod 1 vozdeystviya na konstruktsii Chast' 1-5. Obschie vozdeystviya. Temperaturnye vozdeystviya (2009). Ministerstvo arhitektury i stroitel'stva Respubliki Belarus'. Minsk, 38.
15. Metodicheskie rekomendatsii po primeneniyu metallicheskih trub bol'shogo diametra v usloviyah naledeobrazovaniya i mnogoletnemerzlyh gruntov (dlya opytno-eksperimental'nogo stroitel'stva) (2003). Moscow, 65.
16. Kovalchyk, Y. I. (2016). Recommendations of design and construction technology of monolithic post-tensioned concrete bridge spans. SWorld.
17. Dmytrychenko, M. F., Dmytriev, M. M., Derkachov, O. B. (2012). Teplova diahnostyka (osnovy teoriyi ta praktyky zastosuvannia). Kyiv: NTU, 168.
18. Ovchinnikov, I. G., Scherbakov, A. G., Bochkarev, A. V., Naumova, G. A. (2006). Prikladnaya mekhanika dorozhnyh odezhd na mostovyh sooruzheniyah. Volgograd: VolgGASU, 310.
19. Bogomolov, V., Abramchuk, F., Raznitzyn, I. et. al. (2014). On the steady-state temperature field of multilayer road pavement. Vestnik HNADU, 67, 94–97.
20. Feng, T., Feng, S. (2012). A Numerical Model for Predicting Road Surface Temperature in the Highway. Procedia Engineering, 37, 137–142. doi: https://doi.org/10.1016/j.proeng.2012.04.216
21. Design Criteria Skyway Structures (2001). San Francisco-Oakland Bay Bridge East Span Seismic Safety Project, 91.
22. Stankevych, V. Z., Butrak, I. O., Kovalchuk, V. V. (2018). Cracks Interaction in the Elastic Composite under Action of the Harmonic Loading Field. 2018 XXIIIrd International Seminar/Workshop on Direct and Inverse Problems of Electromagnetic and Acoustic Wave Theory (DIPED). doi: https://doi.org/10.1109/diped.2018.8543323
23. De Backer, H., Outtier, A., Van Bogaert, Ph. (2009). Numerical and experimental assessment of thermal stresses in steel box girders. Civil Engineering Department, Universiteit Gent, Gent, Belgium NSCC, 65–72.
24. Balmes, E., Corus, M., Siegert, D. (2006). Modeling thermal effects on bridge dynamic responses. Ecole Centrale Paris.
25. Burdet, O. L. (2010). Thermal Effects in the Long-Term Monitoring of Bridges. IABSE Symposium Report, 97 (19), 62–68. doi: https://doi.org/10.2749/222137810796025465
26. Sysyn, M. P., Kovalchuk, V. V., Jiang, D. (2019). Performance study of the inertial monitoring method for railway turnouts. International Journal of Rail Transportation, 7 (2), 103–116. doi: https://doi.org/10.1080/23248378.2018.1514282
27. Teplovizor testo 875. Rukovodstvo po ekspluatatsii. Available at: https://www.geo-st.ru/upload/iblock/f46/f46af0056a0c67d9b73d5dd617627d85.pdf
28. Pirometr NT-822. Rukovodstvo po ekspluatatsii (2012).
29. Bek, Dzh., Blakuell, B., Sent-Kler, ml. (1989). Nekorrektnye obratnye zadachi teploprovodnosti. Moscow: Mir, 312.
30. Burak, Ya., Chaplia, Ye., Gera, B. (1996). Thermodynamic models and investigation methods of heterophase

multicomponent systems. XXXV Sympozjon «Modelowanie w mechanice». Gliwice: Politechnika Slaska, 29–34.
31. D'yarmati, K. (1974). Neravnovesnaya termodinamika. Moscow: Mir, 304.
32. Rudakov, K. M. (2009). Vstup u UGS Femap 9.3 (dlia Windows). Heometrychne ta skinchenno-elementna modeliuvannia konstruktsiy. Kyiv: NTUU «KPI», 282.
33. Podstrigach, Ya. S., Shvets, R. N. (1978). Termouprugost' tonkih obolochek. Kyiv: Naukova dumka, 343.
34. Kovalchuk, V. V. (2014). Osnovni zasady rozrakhunku metalevykh hofrovanykh konstruktsiy metodom skinchennykh elementiv pry vzaiemodiyi z hrutovoiu zasypkoiu. Visnyk ODABA, 56, 94–102.
35. Kovalchuk, V. (2015). Finite-element calculation of stress-strain state of corrugated metal structures in the interaction with soil backfill programmed in NX NASTRAN. Visnyk Lvivskoho natsionalnoho ahrarnoho universytetu. Seriya: Arkhitektura i silskohospodarske budivnytstvo, 16, 19–25.
36. Kovalchuk, V., Luchko, J., Bondarenko, I., Markul, R., Parneta, B. (2016). Research and analysis of the stressed-strained state of metal corrugated structures of railroad tracks. Eastern-European Journal of Enterprise Technologies, 6 (7 (84)), 4–9. doi: https://doi.org/10.15587/1729-4061.2016.84236
37. Kovalchuk, V., Markul, R., Bal, O., Milyanych, A., Pentsak, A., Parneta, B., Gajda, A. (2017). The study of strength of corrugated metal structures of railroad tracks. Eastern-European Journal of Enterprise Technologies, 2 (7 (86)), 18–25. doi: https://doi.org/10.15587/1729-4061.2017.96549
38. Kovalchuk, V., Markul, R., Pentsak, A., Parneta, B., Gayda, O., Braichenko, S. (2017). Study of the stress-strain state in defective railway reinforced-concrete pipes restored with corrugated metal structures. Eastern-European Journal of Enterprise Technologies, 5 (1 (89)), 37–44. doi: https://doi.org/10.15587/1729-4061.2017.109611
39. Kovalchuk, V., Kovalchuk, Y., Sysyn, M., Stankevych, V., Petrenko, O. (2018). Estimation of carrying capacity of metallic corrugated structures of the type Multiplate MP 150 during interaction with backfill soil. Eastern-European Journal of Enterprise Technologies, 1 (1 (91)), 18–26. doi: https://doi.org/10.15587/1729-4061.2018.123002

DOI: 10.15587/1729-4061.2019.166490

DETERMINING THE MOST DANGEROUS LOADING APPLICATION POINT FOR ASPHALT-CONCRETE LAYERS ON A RIGID BASE (p. 36–43)

Yevhen Dorozhko
Kharkiv National Automobile and Highway University, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0003-2894-2131

Natalia Arsenieva
Kharkiv National Automobile and Highway University, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-6178-2558

Hor Sarkisian
Kharkiv National Automobile and Highway University, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0003-2343-4461

Oksana Synovets
Kharkiv National Automobile and Highway University, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-3546-066X

Operating conditions of asphalt-concrete layers on cement-concrete slabs differ significantly from other structural solutions. Practical road construction applies the insufficiently developed methods for calculating the strength of asphalt-concrete coating for rigid road beds since only separate strength criteria of the asphalt-concrete layer are standardized. Current calculation methods do not take into consideration the patterns in the stressed-strained state of an asphalt-concrete layer on cement-concrete slabs under various conditions for the application of load, such as the middle part of a slab, the edge of a slab, and the corner of a slab. The mismatch between the conditions for calculation and the actual stressed-deformed state of a structure predetermines the premature failure of an asphalt-concrete layer and, consequently, shortens the inter-maintenance period and leads to additional costs for unplanned repair.

We have simulated the stressed-strained state of a road bed structure by using a finite-element method in the programming environment ANSYS for three variants of arrangement of transport loading, specifically in the center of a slab, at the edge of a slab, and in the corner of a slab.

The paper provides, for the accepted variants of the transport loading, the derived values for the von Mises stresses, principal stresses, horizontal and maximal horizontal shear stresses. The stresses' values were determined at the surface of an asphalt-concrete layer, at a point of contact between an asphalt-concrete layer and a cement-concrete slab, and at a contact point between a cement-concrete slab and a base.

We have compared the defined stresses in the layers of a road bed for different variants of the application of a transport loading, as well as compared the results obtained with known solutions.

That has made it possible to establish that for the asphalt-concrete layer the arrangement of load in the corner of slab is the most dangerous, both in terms of shear stresses and the von Mises stresses. The stresses that occur when the load is applied at the corner of a slab are approximately 10 % higher than the stresses that occur when the load is applied at the edge of a slab, and are approximately 20 % higher than the stresses arising when the load is applied in the center of a slab.

Keywords: asphalt-concrete layer, modulus of elasticity, stressed-strained state, load application point, cement-concrete slab.

References

1. Radovskiy, B. S. (2010). Opyt ispol'zovaniya starogo cementobetona kak osnovaniya pod asfal'tobetonnoe pokrytie v SShA. Dorozhnaya tekhnika, 1, 20–32.
2. Hameliak, I. P., Koretskyi, A. S., Koretskyi, S. S. (2013). Pro neobkhidnist budivnytstva v Ukraini avtomobilnykh dorih iz tsementobetonnym pokryttiam. Avtoshliakhovyk Ukrainy, 5, 24–31.
3. Korochkin, A. V., Ahmetov, S. A. (2009). Zavisimost' sostoyaniya pokrytiya ot tolschiny asfal'tobetonnyh sloev zhestkoy dorozhnoy odezhdy. Avtomobil'nye dorogi, 12, 27–29.
4. Nevinhlovskyi, V. F. (2013). Teoretychni aspekty rozrakhunku zalyshkovoho resursu asfaltobetonnoho pokryttia na zalizobetonnykh avtodorozhnikh mostakh. Avtomobilni dorohy i dorozhnie budivnytstvo, 89, 225–234.
5. Dorozhko, E., Ryapuhin, V., Makovyey, R. (2016). Design Procedure by Strength Criteria of Asphalt Layers on a Rigid Base Taking into Account the Simultaneous Action of External Loads and Thermal Stresses. Procedia Engineering, 134, 101–108. doi: https://doi.org/10.1016/j.proeng.2016.01.045

6. Onischenko, A., Aksenov, S., Nevynhlovskyy, V. (2016). Numerical Simulation of Stress-Strain State of Asphalt Concrete Pavement on the Carriageway of the South Bridge in Kiev. Procedia Engineering, 134, 322–329. doi: https://doi.org/10.1016/j.proeng.2016.01.014
7. Dorozhko, Ye. V. (2015). Vrakhuvannia sumisnoi diyi zovnishnoho navantazhennia ta temperatury pry rozrakhunkakh tonkykh asfaltobetonnykh shariv na zhorstkiy osnovi. Naukovyi visnyk budivnytstva, 4, 132–136.
8. Hussan, S., Kamal, M. A., Khan, M. B., Irfan, M., Hafeez, I. (2013). Determining the Contribution of Different Structural Layers of Asphalt Pavement System to Rutting Using Transverse Profile Analysis. American Journal of Civil Engineering and Architecture, 1 (6), 174–180. doi: https://doi.org/10.12691/ajcea-1-6-7
9. Volkov, S. S., Vasiliev, A. S., Aizikovich, S. M., Seleznev, N. M., Leontieva, A. V. (2016). Stress–strain state of an elastic soft functionally–graded coating subjected to indentation by a spherical punch. PNRPU Mechanics Bulletin, 4, 20–34. doi: https://doi.org/10.15593/perm.mech/2016.4.02
10. Agallkov, Yu. A., Smirnov, A. V. (1997). Raschet tolschiny asfal'tobetonnyh pokrytiy na zhestkom osnovanii po usloviyam sdviga. Nauka i tekhnika v dorozhnoy otrasli, 5, 7–8.
11. Chen, X., Wu, S., Zhou, J. (2013). Analysis of mechanical properties of concrete cores using statistical approach. Magazine of Concrete Research, 65 (24), 1463–1471. doi: https://doi.org/10.1680/macr.13.00113
12. Shurgaya, A. G., Gamelyak, I. P., Yakimenko, Ya. N. (2015). Vysokoprochnyy cementobeton s kompleksnymi dobavkami dlya dorozhnogo i aerodromnogo stroitel'stva. Avtomobil'nye dorogi i mosty, 2 (16), 34–42.
13. Gameliak, I. P., Shurgaya, A. G., Jakymenko, J. M., Chyzhenko, N. P. (2017). Mathematical models of the properties of high–strength cement – concrete for road construction. Zbirnyk naukovykh prats Ukrainskoho derzhavnoho universytetu zaliznychnoho transportu, 169, 103–110.
14. Riapukhin, V. M., Nechytailo, N. O. (2011). Modeliuvannia napruzheno-deformovanoho stanu asfaltobetonnykh shariv. Mistobuduvannia ta terytorialne planuvannia, 40, 258–263.
15. Golchin, B., Hamzah, M. O., Hasan, M. R. M. (2017). Optimization in producing warm mix asphalt with polymer modified binder and surfactant-wax additive. Construction and Building Materials, 141, 578–588. doi: https://doi.org/10.1016/j.conbuildmat.2017.02.123
16. Bennert, T. (2011). Implementation of Performance-Based HMA Specialty Mixtures in New Jersey. Journal of the Association of Asphalt Paving Technologists, 80, 719–740.
17. Ladygin, B. I. (1970). Prochnost' i dolgovechnost' asfal'tobetona. Minsk, 288.
18. Ryapuhin, V., Nechytaylo, N., Burlachka, V. (2011). Criteria for flexible pavement calculation. TRANSBALTICA 2011: Proceedings of the 7th International Scientific Conference. Vilnius, 252–256.
19. Pisarenko, G. S. (1976). Deformirovanie i prochnost' materialov pri slozhnom napryazhennom sostoyanii. Kyiv, 415.
20. Merzlikin, A. E. Kapustnikov, N. V. (2010). Pogreshnosti, voznikayuschie pri raschete dorozhnyh odezhd s pomosch'yu metoda konechnyh elementov. Stroitel'nye materialy, 10, 26–29.
21. Radovskiy, B. S. (2011). Prochnost' i raschet betonnyh pokrytiy v SShA. Beton i zhelezobeton, 2 (5), 118–131.
22. Radovskiy, B. S. (2009). Cementobetonnye pokrytiya v SShA. Dorozhnaya tekhnika, 1, 50–58.

DOI: 10.15587/1729-4061.2019.169181

A PROCEDURE OF STUDYING STATIONARY MOTIONS OF A ROTOR WITH ATTACHED BODIES (AUTO-BALANCER) USING A FLAT MODEL AS AN EXAMPLE (p. 43–52)

Gennadiy Filimonikhin
Central Ukrainian National Technical University,
Kropyvnytskyi, Ukraine
ORCID: http://orcid.org/0000-0002-2819-0569

Irina Filimonikhina
Central Ukrainian National Technical University,
Kropyvnytskyi, Ukraine
ORCID: http://orcid.org/0000-0002-1384-6027

Iryna Ienina
Central Ukrainian National Technical University,
Kropyvnytskyi, Ukraine
ORCID: http://orcid.org/0000-0002-2122-7808

Serhii Rahulin
Flight Academy of the National Aviation University,
Kropyvnytskyi, Ukraine
ORCID: http://orcid.org/0000-0001-8955-0380

The energy method of studying rotor dynamics has been modernized. The method is applicable to the rotors mounted on isotropic elastic-viscous supports when bodies are attached to the rotors and relative motion of these bodies is prevented by elastic and viscous forces. The method is designed to search for steady motions and determine conditions of their existence as well as assess stability of the rotor system. Relative motions of the attached bodies cease at steady motions and the system rotates as a single whole around the axis of rotation formed by supports.

Effectiveness of the method was illustrated by an example of a flat model of a rotor and an auto-balancer with many loads in the form of balls, rollers or pendulums.

It has been established that the system has family of main motions (the rotor is balanced at them) both with and without damping in supports at a sufficient balancing capacity of the auto-balancer.

In the absence of damping in supports, the system has:

– isolated secondary motions at which the rotor is unbalanced and centers of mass of the loads are deflected to the side of imbalance or in the opposite direction if there is unbalance of the rotor;

– one-parameter families of secondary motions at which the centers of mass of the loads lie on one straight line in the absence of unbalance of the rotor.

In the presence of damping in supports:

– the system has isolated secondary motions at which the centers of mass of the loads lie on one straight line and this straight line forms an angle with the imbalance vector depending on the rotor speed in the presence of the rotor imbalance;

– there are no secondary motions in the absence of the rotor imbalance.

The secondary motions and domains of their existence do not depend on the angular velocity of the rotor in the absence of damping in supports but they depend on the angular velocity of the rotor in the presence of the rotor imbalance.

Both in the presence and in the absence of damping in supports:

– only the secondary motion at which total imbalance of the rotor and loads is greatest can be stable at sub-resonant rotor speeds;

– only a family of main motions can be stable at super-resonant rotor speeds.

Keywords: rotor, isotropic support, auto-balancer, stationary motion, stability of motion, equation of steady motion.

References

1. Thearle, E. L. (1950). Automatic dynamic balancers (Part 2 – Ring, pendulum, ball balancers). Machine Design, 22 (10), 103–106.
2. Gusarov, A. A. (2002). Avtobalansiruyuschie ustroystva pryamogo deystviya. Moscow: Nauka, 119.
3. Filimonikhin, G. B. (2004). Zrivnovazhennia i vibrozakhyst rotoriv avtobalansyramy z tverdymy koryhuvalnymy vantazhamy. Kirovohrad: KNTU, 352.
4. Detinko, F. M. (1956). Ob ustoychivosti raboty avtobalansira dlya dinamicheskoy balansirovki. Izv. AN SSSR. OTN. Mekh. i Mashinostr, 4, 38–45.
5. Muyzhniek, A. I. (1956). Nekotorye voprosy teorii avtomaticheskoy dinamicheskoy balansirovki. Voprosy dinamiki i prochnosti, 6, 123–145.
6. Blekhman, I. I. (1981). Sinhronizatsiya v prirode i tekhnike. Moscow: Nauka, 352.
7. Nesterenko, V. P. (1985). Avtomaticheskaya balansirovka rotorov priborov i mashin so mnogimi stepenyami svobody. Tomsk: Izd-vo Tomsk. un-ta, 84.
8. Filimonikhin, G. B. (1996). K ustoychivosti osnovnogo dvizheniya dvuhmayatnikovogo avtobalansira. Dopovidi Natsionalnoi akademiyi nauk Ukrainy, 8, 74–78. Available at: http://dspace.kntu.kr.ua/jspui/handle/123456789/6796
9. Gorbenko, A. N. (2003). On the Stability of Self-Balancing of a Rotor with the Help of Balls. Strength of Materials, 35 (3), 305–312. doi: http://doi.org/10.1023/a:1024621023821
10. Filimonikhina, I. I. (2006). Zastosuvannia funktsiyi Hamiltona do vyznachennia umov nastannia avtobalansuvannia rotora z nerukhomoiu tochkoiu. Konstruiuvannia, vyrobnytstvo ta ekspluatatsiya silskohospodarskykh mashyn, 36, 241–246.
11. Green, K., Champneys, A. R., Lieven, N. J. (2006). Bifurcation analysis of an automatic dynamic balancing mechanism for eccentric rotors. Journal of Sound and Vibration, 291 (3-5), 861–881. doi: https://doi.org/10.1016/j.jsv.2005.06.042
12. Ruelle, D. (1989). Elements of Differentiable Dynamics and Bifurcation Theory. Academic Press, 196. doi: https://doi.org/10.1016/c2013-0-11426-2
13. Filimonikhin, G. B., Filimonikhina, I. I., Pirogov, V. V. (2014). Stability of Steady-State Motion of an Isolated System Consisting of a Rotating Body and Two Pendulums. International Applied Mechanics, 50 (4), 459–469. doi: https://doi.org/10.1007/s10778-014-0651-9
14. Artyunin, A. I., Eliseyev, S. V. (2013). Effect of «Crawling» and Peculiarities of Motion of a Rotor with Pendular Self-Balancers. Applied Mechanics and Materials, 373-375, 38–42. doi: https://doi.org/10.4028/www.scientific.net/amm.373-375.38
15. Antipov, V. I., Dentsov, N. N., Koshelev, A. V. (2014). Dynamics of the parametrically excited vibrating machine with isotropic elastic system. Fundamental'nye issledovaniya, 8, 1037–1042. Available at: http://www.fundamental-research.ru/ru/article/view?id=34713
16. Lu, C.-J., Wang, M.-C. (2011). Stability analysis of a ball-rod-spring automatic balancer. International Journal of Mechanical Sciences, 53 (10), 846–854. doi: https://doi.org/10.1016/j.ijmecsci.2011.07.005
17. Rezaee, M., Mohammad Ettefagh, M., Fathi, R. (2019). Dynamics and Stability of Non-Planar Rigid Rotor Equipped with Two Ball-Spring Autobalancers. International Journal of Structural Stability and Dynamics, 19 (02), 1950001. doi: https://doi.org/10.1142/s0219455419500019
18. Strauch, D. (2009). Classical Mechanics: An Introduction. Springer-Verlag Berlin Heidelberg. doi: https://doi.org/10.1007/978-3-540-73616-5

DOI: 10.15587/1729-4061.2019.168909

MODELING THE RESONANCE OF A SWINGING SPRING BASED ON THE SYNTHESIS OF A MOTION TRAJECTORY OF ITS LOAD (p. 53–64)

Leonid Kutsenko
National University of Civil Defense
of Ukraine, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0003-1554-8848

Volodymyr Vanin
National Technical University of Ukraine
«Igor Sikorsky Kyiv Polytechnic Institute», Kyiv, Ukraine
ORCID: http://orcid.org/0000-0001-7008-7269

Olga Shoman
National Technical University
«Kharkiv Polytechnic Institute», Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-3660-0441

Petro Yablonskyi
National Technical University of Ukraine
«Igor Sikorsky Kyiv Polytechnic Institute», Kyiv, Ukraine
ORCID: http://orcid.org/0000-0002-1971-5140

Leonid Zapolskiy
The Ukrainian Civil Protection
Research Institute, Kyiv, Ukraine
ORCID: http://orcid.org/0000-0003-4357-2933

Natalia Hrytsyna
Kharkiv National Automobile and
Highway University, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-2043-6085

Sergii Nazarenko
National University of Civil Defense
of Ukraine, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0003-0891-0335

Volodymyr Danylenko
National Technical University
«Kharkiv Polytechnic Institute», Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0003-4952-7498

Elizaveta Sivak
National Technical University
«Kharkiv Polytechnic Institute», Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-5526-8544

Serhii Shevchenko
National University of Civil Defense
of Ukraine, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-6740-9252

The paper reports a technique for building the resonance trajectories of the motion of a swinging spring load. A swinging spring is the kind of a mathematical pendulum consisting of a point load attached to a weightless spring. The other end of the spring is fixed immovably. We have considered the pendulum-like spring oscillations in a vertical plane provided its axis straightness is maintained. Calculations have been performed based on the solutions to a system of differential equations with components that include values for the frequency values of vertical and horizontal displacements of a point on a spring.

The relevance of the subject is predetermined by the necessity to study the technological processes of dynamic systems when the nonlinearly connected oscillatory components of the system exchange energy. Using a swinging spring phenomenon illustrates the exchange of energies between the transverse (pendulum) and longitudinal (spring) oscillations. In this case, we also take into consideration the influence of the initial conditions for initiating oscillations. Of particular importance is to study the resonance state of a swinging spring when the frequency of longitudinal oscillations differs by a multiple number of times from the frequency of transverse oscillations. In addition to a common «classic» case (resonance 2:1), there is a need to consider cases with different values for the frequency ratio. The result is the derived geometric shapes of the motion trajectory of a swinging spring load that correspond to the patterns in the state of its resonance.

The results obtained in the current paper make it possible, by using a computer, to synthesize the motion trajectory of a swinging spring load that would match the assigned frequency ratio of longitudinal and transverse oscillations. For this purpose, in addition to basic parameters (a load's mass, rigidity of the spring, its length in a no-load state), we added the initial values for the parameters during oscillation initiation. Specifically, the «starting» coordinates for a load position, and the initial load motion velocities in the direction of the coordinate axes. We have considered examples of building a load motion's trajectories for cases of resonances the type of 2:1, 7:3; 9:4; and 11:2. The results obtained are illustrated by the computerized animations of oscillations of appropriate swinging springs for different cases of resonance.

The results could be used as a paradigm in order to study the nonlinear connected systems, as well as in the calculation of variants for mechanical devices where springs affect the oscillation of their elements. Additionally, for cases when the technology of using mechanical devices necessitates abandoning the chaotic movements of loads in order to ensure the periodic trajectories of their displacements.

Keywords: swinging spring, a swinging spring resonance, pendulum oscillations, a load motion's trajectories.

References

1. Kutsenko, L., Semkiv, O., Kalynovskyi, A., Zapolskiy, L., Shoman, O., Virchenko, G. et. al. (2019). Development of a method for computer simulation of a swinging spring load movement path. Eastern-European Journal of Enterprise Technologies, 1 (7 (97)), 60–73. doi: https://doi.org/10.15587/1729-4061.2019.154191
2. Kutsenko, L., Vanin, V., Shoman, O., Zapolskiy, L., Yablonskyi, P., Vasyliev, S. et. al. (2019). Synthesis and classification of periodic motion trajectories of the swinging spring load. Eastern-European Journal of Enterprise Technologies, 2 (7 (98)), 26–37. doi: https://doi.org/10.15587/1729-4061.2019.161769
3. De Sousa, M. C., Marcus, F. A., Caldas, I. L., Viana, R. L. (2018). Energy distribution in intrinsically coupled systems: The spring pendulum paradigm. Physica A: Statistical Mechanics and its Applications, 509, 1110–1119. doi: https://doi.org/10.1016/j.physa.2018.06.089
4. De Sousa, M. C. de S., Marcus, F. A. M., Caldas, I. L. C. (2016). Energy distribution in a spring pendulum. Proceedings of the 6th International Conference on Nonlinear Science and Complexity. doi: https://doi.org/10.20906/cps/nsc2016-0022
5. De Sousa, M. C., Marcus, F. A., Caldas, I. L., Viana, R. L. (2017). Energy Distribution in Spring Pendulums. Available at: https://www.researchgate.net/publication/316187700_Energy_Distribution_in_Spring_Pendulums
6. Buldakova, D. A., Kiryushin, A. V. (2015). Model of the shaking spring pendulum in the history of physics and equipment. Elektronnoe nauchnoe izdanie «Uchenye zametki TOGU», 6 (2), 238–243.
7. Ganis, L. (2013). The Swinging Spring: Regular and Chaotic Motion. Available at: http://depts.washington.edu/amath/wordpress/wp-content/uploads/2014/01/leah_ganis_pres.pdf
8. Sanders, J. A., Verhulst, F., Murdock, J. (2007). Averaging Methods in Nonlinear Dynamical Systems. Springer, 434. doi: https://doi.org/10.1007/978-0-387-48918-6
9. Kolebaniya tipa «gollandskiy shag» voznikayut, kogda poperechnaya ustoychivost' samoleta velika, po sravneniyu s putevoy ustoychivost'yu. Available at: http://studepedia.org/index.php?vol=3&post=13634
10. Li-Juan, Z., Hua-Biao, Z., Xin-Ye, L. (2018). Periodic solution and its stability of spring pendulum with horizontal base motion. Acta Physica Sinica, 67 (24). doi: http://doi.org/10.7498/aps.67.20181676
11. Lynch, P.; Norbury, J., Roulstone, I. (Eds.) (2002). The swinging spring: a simple model of amospheric balance. Large-Scale Atmosphere-Ocean Dynamics. Vol. II: Geometric Methods and Models. Cambridge University Press, 64–108.
12. Lynch, P., Houghton, C. (2004). Pulsation and precession of the resonant swinging spring. Physica D: Nonlinear Phenomena, 190 (1-2), 38–62. doi: https://doi.org/10.1016/j.physd.2003.09.043
13. Kartashova, E. (2010). Nonlinear resonance analysis. Theory, Computation, Applications. Cambridge University Press, 241. doi: https://doi.org/10.1017/cbo9780511779046
14. Kuznetsov, S. V. (1999). The Motion of the Elastic Pendulum. Regular and Chaotic Dynamics, 4 (3), 3–12. doi: https://doi.org/10.1070/rd1999v004n03abeh000110
15. Klimenko, A. A., Mikhlin, Yu. V. (2009). Nonlinear dynamics of the spring pendulum. Dinamicheskie sistemy, 27, 51–65.
16. Cross, R. (2017). Experimental investigation of an elastic pendulum. European Journal of Physics, 38 (6), 065004. doi: https://doi.org/10.1088/1361-6404/aa8649
17. Lynch, P. (2002). Resonant motions of the three-dimensional elastic pendulum. International Journal of Non-Linear Mechanics, 37 (2), 345–367. doi: https://doi.org/10.1016/s0020-7462(00)00121-9
18. Lynch, P. (2009). On resonant Rossby-Haurwitz triads. Tellus A, 61 (3), 438–445. doi: https://doi.org/10.1111/j.1600-0870.2009.00395.x
19. Devaux, P., Piau, V., Vignaud, O., Grosse, G., Olarte, R., Nuttin, A. (2019). Cross-camera tracking and frequency analysis of a cheap Slinky Wilberforce pendulum. Emergent Scientist, 3, 1. doi: https://doi.org/10.1051/emsci/2018006
20. Berg, R. E., Marshall, T. S. (1991). Wilberforce pendulum oscillations and normal modes. American Journal of Physics, 59 (1), 32–38. doi: https://doi.org/10.1119/1.16702

21. Köpf, U. (1990). Wilberforce's pendulum revisited. American Journal of Physics, 58 (9), 833–837. doi: https://doi.org/10.1119/1.16376
22. Dobrushkin, V. Spring Pendulum. Available at: http://www.cfm.brown.edu/people/dobrush/am34/Mathematica/ch3/pendulum.html
23. Ivanov, I. (2015). Kolebaniya pruzhinnogo mayatnika. Available at: https://elementy.ru/problems/1006/kolebaniya_pruzhinnogo_mayatnika
24. Richterek, L. (2007). Dynamicke modelovani modelovani v programu gnu octave. Available at: http://muj.optol.cz/richterek/lib/exe/fetch.php?media=texty:dynmod.pdf
25. Lepil, O., Richterek, L. (2007). Dynamicke modelovani. Slovanské gymnázium Olomouc, 161. Available at: https://www.researchgate.net/publication/40356351
26. Havránek, A. Pruzne kyvadlo – vysetrovani bifurkace metodami newtonovske mechaniky. Available at: https://web.vscht.cz/pokornp/h/PrzkvHerb2.doc
27. Dvořák, L. (2006). Pružné kyvadlo: od teoretické mechaniky k pokusům a zase zpátky. Pokroky matematiky, fyziky a astronomie, 51 (4), 312–327.
28. Havránek, A., Čertík, O. (2006). Pružné kyvadlo. Pokroky matematiky, fyziky a astronomie, 51 (3), 198–216.
29. Kutsenko, L. M., Piksasov, M. M., Zapolskyi, L. L. (2018). Iliustratsiyi do statti «Heometrychne modeliuvannia periodychnoi traiektoriyi vantazhu khytnoi pruzhyny». Available at: http://repositsc.nuczu.edu.ua/handle/123456789/7637
30. Kutsenko, L. M., Piksasov, M. M., Vasyliev, S. V. (2019). Iliustratsiyi do statti «Klasyfikatsiya elementiv simi periodychnykh traiektoriy rukhu vantazhu khytnoi pruzhyny». Available at: http://repositsc.nuczu.edu.ua/handle/123456789/8658
31. Kutsenko, L. M., Piksasov, M. M., Shevchenko, S. M. (2019). Iliustratsiyi do statti «Modeliuvannia rezonansu khytnoi pruzhyny na osnovi syntezu traiektoriyi rukhu yii vantazhu». Available at: http://repositsc.nuczu.edu.ua/handle/123456789/8950
32. Kalinichenko, V. A., Aung Naing So, A. N. S. (2013). Faraday waves in a movable tank and their mechanical analog. Engineering Journal: Science and Innovation, 12. doi: https://doi.org/10.18698/2308-6033-2013-12-1138

DOI: 10.15587/1729-4061.2019.166944

OPTIMIZATION OF ANGULAR VELOCITY OF DRUM MIXERS (p. 64–72)

Gennadii Golub
National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine
ORCID: http://orcid.org/0000-0002-2388-0405

Yaroslav Myhailovych
National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine
ORCID: http://orcid.org/0000-0003-0373-2736

Oksana Achkevych
National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine
ORCID: http://orcid.org/0000-0001-9878-6563

Viacheslav Chuba
National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine
ORCID: http://orcid.org/0000-0002-4119-0520

Drum mixers ensure a high level of uniformity when mixing the components of feed additives. However, the issues on theoretical and experimental substantiation of the structural and kinematic parameters of drum mixers have not been scientifically explored in detail. The aim of this study is to improve the efficiency of producing feed mixtures by ensuring the optimal angular rotation velocity of a drum mixer.

To determine the radial speed of a particle's motion along a drum blade, we solved a homogeneous differential equation. The numerical value for angular velocity was determined by a computer simulation method. We experimentally studied the uniformity of redistribution of feed components in a mixture of fodder using the designed experimental drum mixer. The mixer included a chamber, a rectangular frame, a supporting frame, and a drive. The mixing chamber included a loading/unloading window with a closed lid. Radial blades were installed inside the chamber along its entire length and evenly along the perimeter.

Experiments were conducted using a drum mixer with a drum radius of 0.17 m, which included radial blades with a width of 25 mm, with a chamber's fill factor of 0.5. It was established that the drum mixer ensures the maximum scattering of a material's particles on the surface of the working segment at the drum's angular rotation velocity of 9.69 rad/s.

The results of experimental research have established that at rotation frequency of the laboratory plant's drum of 9.42 rad/s the uniformity of mixture is 92.5–93 %, which meets acting zootechnical requirements for all types of mixed fodder. In this case, a maximum deviation of the theoretical and experimental data was about 9 %. The results obtained suggest the possibility of determining a numerical value for the angular velocity of drum mixers by using the proposed method of computer simulation.

Keywords: blade, radial velocity, fill factor, mixing time, feed additives, control component, mixture, drum radius.

References

1. Krasnov, I. N., Filin, V. M., Globin, A. N., Ladygin, E. A. (2014). Proizvodstvo kombikormov v usloviyah lichnyh podsobnyh i fermerskih hozyaystv. Zernograd: FGBOU VPO ACHGAA, 228.
2. Dudka, S., Toshynskiy, V. (2012). Research of granulation and drying process in technology of fertilizer «Superagro N: P 10:40». Eastern-European Journal of Enterprise Technologies, 4 (6 (58)), 7–10. Available at: http://journals.uran.ua/eejet/article/view/5583/5023
3. Tereshkin, O., Horielkov, D., Dmytrevskyi, D., Chervonyi, V. (2016). Modeling of mechanical treatment of napiform onion to determine the rational parameters of its cleaning. Eastern-European Journal of Enterprise Technologies, 6 (11 (84)), 30–39. doi: https://doi.org/10.15587/1729-4061.2016.86472
4. Makarov, Yu. I., Sal'nikova, G. D. (1993). Osnovnye tendencii sovershenstvovaniya otechestvennogo, oborudovaniya dlya smeshivaniya sypuchih materialov. Neftyanoe i himicheskoe mashinostroenie, 10, 5–8.
5. Lu, G., Third, J. R., Müller, C. R. (2015). Discrete element models for non-spherical particle systems: From theoretical developments to applications. Chemical Engineering Science, 127, 425–465. doi: https://doi.org/10.1016/j.ces.2014.11.050

6. Liu, P. Y., Yang, R. Y., Yu, A. B. (2013). DEM study of the transverse mixing of wet particles in rotating drums. Chemical Engineering Science, 86, 99–107. doi: https://doi.org/10.1016/j.ces.2012.06.015
7. Norouzi, H. R., Zarghami, R., Mostoufi, N. (2015). Insights into the granular flow in rotating drums. Chemical Engineering Research and Design, 102, 12–25. doi: https://doi.org/10.1016/j.cherd.2015.06.010
8. Zhang, Z., Gui, N., Ge, L., Li, Z. (2017). Numerical study of mixing of binary-sized particles in rotating tumblers on the effects of end-walls and size ratios. Powder Technology, 314, 164–174. doi: https://doi.org/10.1016/j.powtec.2016.09.072
9. Ma, H., Zhao, Y. (2017). Modelling of the flow of ellipsoidal particles in a horizontal rotating drum based on DEM simulation. Chemical Engineering Science, 172, 636–651. doi: https://doi.org/10.1016/j.ces.2017.07.017
10. Gui, N., Yang, X., Tu, J., Jiang, S. (2017). Numerical simulation and analysis of mixing of polygonal particles in 2D rotating drums by SIPHPM method. Powder Technology, 318, 248–262. doi: https://doi.org/10.1016/j.powtec.2017.06.007
11. Qi, H., Xu, J., Zhou, G., Chen, F., Ge, W., Li, J. (2015). Numerical investigation of granular flow similarity in rotating drums. Particuology, 22, 119–127. doi: https://doi.org/10.1016/j.partic.2014.10.012
12. Gan, J. Q., Zhou, Z. Y., Yu, A. B. (2016). A GPU-based DEM approach for modelling of particulate systems. Powder Technology, 301, 1172–1182. doi: https://doi.org/10.1016/j.powtec.2016.07.072
13. Li, S., Yao, Q., Chen, B., Zhang, X., Ding, Y. L. (2007). Molecular dynamics simulation and continuum modelling of granular surface flow in rotating drums. Chinese Science Bulletin, 52 (5), 692–700. doi: https://doi.org/10.1007/s11434-007-0069-4
14. Zheng, Q. J., Yu, A. B. (2015). Modelling the granular flow in a rotating drum by the Eulerian finite element method. Powder Technology, 286, 361–370. doi: https://doi.org/10.1016/j.powtec.2015.08.025
15. Delele, M. A., Weigler, F., Franke, G., Mellmann, J. (2016). Studying the solids and fluid flow behavior in rotary drums based on a multiphase CFD model. Powder Technology, 292, 260–271. doi: https://doi.org/10.1016/j.powtec.2016.01.026
16. Naumenko, Y., Sivko, V. (2017). The rotating chamber granular fill shear layer flow simulation. Eastern-European Journal of Enterprise Technologies, 4 (7 (88)), 57–64. doi: https://doi.org/10.15587/1729-4061.2017.107242
17. Sheng, L.-T., Chang, W.-C., Hsiau, S.-S. (2016). Influence of particle surface roughness on creeping granular motion. Physical Review E, 94 (1). doi: https://doi.org/10.1103/physreve.94.012903
18. Chou, H.-T., Lee, C.-F. (2009). Cross-sectional and axial flow characteristics of dry granular material in rotating drums. Granular Matter, 11 (1), 13–32. doi: https://doi.org/10.1007/s10035-008-0118-y
19. Makevnin, M. P., Pershin, V. F., Sviridov, M. M. (1984). Raschet vremeni padeniya chastic sypuchego materiala v barabannyh sushilkah s lopastnoy nasadkoy. Himicheskoe i neftyanoe mashinostroenie, 9, 31–32.
20. Golub, G., Pavlenko, S., Kukharets, S. (2017). Analytical research into the motion of organic mixture components during formation of compost clamps. Eastern-European Journal of Enterprise Technologies, 3 (1 (87)), 30–35. doi: https://doi.org/10.15587/1729-4061.2017.101097

DOI: 10.15587/1729-4061.2019.169944

DETERMINING THE PARAMETERS FOR CONNECTIONS AMONG THE ELEMENTS OF DESIGN OF VEHICLES IN TERMS OF ERGONOMICS AND CREW SAFETY (p. 72–80)

Valeriy Pisarev
National Academy of National Guard of Ukraine, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0003-3396-1492

This paper reports a study into the working processes of the system «operator – machine – external environment» in land vehicles using the constructed mathematical model.

A significant effect has been determined that the structure and parameters of relations between elements of the design exerts on meeting the requirements for ergonomics and safety for crews.

The results from numerical experiment have proven the need for an integrated approach at the design phase (modernization) when defining the parameters for the examined object (an example of such an object has been considered with parameters close to the parameters for BTR-60...BTR-80).

Feature of the integrated approach is that the requirements regarding ergonomics and the safety requirements have been met simultaneously. From the standpoint of ergonomics, the parameters for ride smoothness, accommodation of an operator (for example, a driver) relative to machine's controls, were regulated and, in general, within a control cabin, taking into consideration its arrangement. From the standpoint of safety, the parameters were regulated for the case of a landmine explosion.

It has been shown that the framework of the applied procedure for optimal design of complex technical systems allows the implementation of the examined object (upgrade) that would comply with the requirements for both ergonomics and safety of crews.

The accomplishment of the goal has been confirmed by the calculation results in the form of oscillograms (displacements, velocities, accelerations, forces) for working processes aimed at transforming the force action from a disturbing factor along the way from a wheeled vehicle to operator.

The mathematical model makes it possible to quantify and to qualitatively estimate the role of the main parameters for the entire object, and, specifically, the elastic damping relations at two levels (the first level is cushioning a machine's body, the second level is cushioning the seat of an operator).

The numerical experiment was conducted using a Runge-Kutta method with a variable step employing an original software.

Keywords: operator, vehicle, disturbing factor, explosion, ergonomics, safety.

References

1. Medvedkov, V. I. (1976). Teoriya, konstruktsiya i raschet boevyh kolesnyh mashin. Moscow, 405.
2. Rotenberg, R. V. (1972). Podveska avtomobilya. Moscow, 392.
3. Burov, S. S. (1973). Konstruktsiya i raschet tankov. Moscow: Izdanie akademii bronetankovyh voysk, 601.
4. Owens, B. D., Kragh, J. F. Jr., Macaitis, J., Svoboda, S. J., Wenke, J. C. (2007). Characterization of extremity wounds in Operation Iraqi Freedom and Operation Enduring Freedom. Journal of Orthopaedic Trauma, 21 (4), 254–257.

5. Zouris, J. M., Walker, G. J., Dye, J., Galarneau, M. (2006). Wounding Patterns for U.S. Marines and Sailors during Operation Iraqi Freedom, Major Combat Phase. Military Medicine, 171 (3), 246–252. doi: https://doi.org/10.7205/milmed.171.3.246
6. Geertz, A. (1946). Limits and Special Problems in the Use of Seat Catapults. United States Army Air Forces. Aero Medical Center. Heidelberg, 112.
7. Ruff, S. (1950). Brief Acceleration: Less than One Second. German Aviation Medicine, 1, 584–598.
8. Code of Federal Regulations title 14 part 23 (23.562). Airworthiness standards: normal, utility, acrobatic, and commuter category airplanes. Available at: http://www.law.cornell.edu/cfr/text/14/23.562
9. Code of Federal Regulations title 14 part 25 (25.562). Airworthiness standards: transport category airplanes. Available at: http://www.law.cornell.edu/cfr/text/14/25.562
10. Code of Federal Regulations title 14 part 27 (27.562). Airworthiness standards: normal category rotorcraft. Available at: Available at: http://www.law.cornell.edu/cfr/text/14/27.562
11. Code of Federal Regulations title 14 part 29 (29.562). Airworthiness standards: transport category rotorcraft. Available at: http://www.law.cornell.edu/cfr/text/14/29.562
12. Kulakov, N. A., Shevchenko, A. A. (2012). Evaluation of explosive impact of mines on structures and crews of armored vehicles. Damaging effects. Methods of protection. Izvestiya MGTU «MAMI», 1 (2 (14)), 194–205.
13. Kulakov, N. A. (2008). Vozdeystvie dinamicheskoy nagruzki na nazemnye transportnye sredstva. Izbrannye problemy prochnosti sovremennogo mashinostroeniya. Moscow: Fizmatlit, 204.
14. Gavrilov, E. V. (2017). Razrabotka nauchno obosnoavnnyh resheniy zadach zaschity ekipazhey avtobronetankovoy tekhniki pri minno – vzryvnom vozdeystvii. Moscow, 217.
15. Pisariev, V. P. (2013). Modeliuvannia protsesu pidryvu boiovoi kolisnoi mashyny u vypadku naizdu na minu. Zbirnyk naukovykh prats Akademiyi vnutrishnikh viysk MVS Ukrainy, 1, 5–8.
16. Korolev, G. E., Mamleev, R. Z. (1991). Issledovanie boevyh povrezhdeniy obraztsov otechestvennoy BTT. Vestnik bronetankovoy tekhniki, 8.
17. Pisariev, V. P. (2011). Mozhlyvosti transportnoho zasobu z halmuvannia za vidsutnistiu proboiu pidvisky. Vestnik NTU «KhPI». Sbornik nauchnyh trudov. Tematicheskiy vypusk «Avtomobile- i traktorostroenie», 56, 29–33.
18. Pisariev, V. P. (2013). Otsiniuvannia stupenia mozhlyvoi urazhenosti ekipazhu boiovoi kolisnoi mashyny za mistsem yoho roztashuvannia u razi pidryvu na mini. Chest i zakon, 1, 91–93.
19. Pisariev, V. P. (2015). Otsiniuvannia stiykosti rukhu boiovoi kolisnoi mashyny za perekhidnymy ta stalymy stanamy v rezhymi povorotu. Zbirnyk naukovykh prats Natsionalnoi akademiyi Natsionalnoi hvardiyi Ukrainy, 2, 15–26.
20. Report on experimental design work on the topic: «Dynamic Performance of a Variable Load Energy Absorber» (1982). Aircraft and Crew Systems Technology Directorate, Naval Air Development Center. Pennsylvania, 51.
21. Report on experimental design work on the topic: «Design and Development of Variable-Load Energy Absorbers» (1981). Aircraft and Crew Systems Technology Directorate, Naval Air Development Center. Pennsylvania, 43.
22. Vil'son, U. Ker. (1963). Vibratsionnaya tekhnika. Prakticheskoe rukovodstvo po uravnoveshivaniyu dvigateley, mekhanicheskim kolebaniyam i vibroizolyatsii. Moscow, 415.
23. Pokrovskiy, G. I. (1960). Vzryv i ego primenenie. Moscow, 67.
24. Pokrovskiy, G. I. (1980). Vzryv. Moscow, 192.