ABSTRACT AND REFERENCES

APPLIED MECHANICS

DOI: 10.15587/1729-4061.2017.99823

DETERMINING THE CHARACTERISTICS OF VISCOUS FRICTION IN THE SLIDING SUPPORTS USING THE METHOD OF PENDULUM (p. 4-10)

Aleksandr Dykha
Khmelnitskyi National University, Khmelnitskyi, Ukraine
ORCID: http://orcid.org/0000-0003-3020-9625

Viktor Aulin
Central-Ukrainian National
Technical University, Kropyvnytskyi, Ukraine
ORCID: http://orcid.org/0000-0003-2737-120X

Oleg Makovkin
Khmelnitskyi National University, Khmelnitskyi, Ukraine
ORCID: http://orcid.org/0000-0003-4487-7448

Sergiy Posonskiy
Khmelnitskyi National University, Khmelnitskyi, Ukraine
ORCID: http://orcid.org/0000-0002-4697-7699

We analyzed the methods of determining the characteristics of friction based on the experimental studies using the damped oscillations of a pendulum. It was established that the available studies into characteristics of viscous friction lack the analytical description of the process of damped oscillations at viscous resistance and recommendations regarding practical calculation of the characteristics of friction. Here we propose a theoretical model of the swinging pendulum in the cylindrical sliding supports with a lubricant. It is demonstrated that for a pendulum in the lubricated sliding supports, the process of oscillations is described by a second order differential equation with viscous resistance, proportional to the deflection velocity of the pendulum.

It is found based on the solution of the equation that the ratio of adjacent amplitudes of damped oscillations is a constant magnitude, hence it follows that the absorption coefficient is constant over the entire process. We established, based on the theoretical model of pendulum oscillations, that for the viscous friction the absorption coefficient is equal to the doubled logarithmic damping decrement and is determined by one or a cycle of oscillations. The formulas are received for calculating the indicator of dynamic viscosity of a lubricant in the contact by the decrement of pendulum oscillations damping. The developed procedures for determining the characteristics of viscous friction are applied to examine the contact- viscous properties of different combinations of lubricating and design materials. The results received are aimed at searching for design and technological solutions in order to reduce the energy losses to friction in the sliding supports of machines.

Keywords: sliding support, method of pendulum, damped oscillations, absorption coefficient, oil viscosity.

References

1. Bhushan, B. (2013). Introduction to Tribology. New York: John Wiley & Sons, 721. 10.1002/9781118403259
2. Dzhilavdari, I. Z., Riznookaya, N. N. (2008). An experimental assessment of the components of rolling friction of balls at small cyclic displacements. Journal of Friction and Wear, 29 (5), 330–334. doi: 10.3103/s1068366608050024
3. Dzhilavdari, I., Riznookaya, N. (2007). Specific features of the dynamics of small-amplitude pendulum swings in the presence of hysteresis friction. Friction and Wear, 2 (28), 143–150.
4. Dzhilavdari, I. Z., Riznookaya, N. N. (2008). Studies of the dynamics of free microoscillations of a pendulum supported by two balls. Journal of Friction and Wear, 29 (1), 1–6. doi: 10.3103/s1068366608010017
5. Kryshtopa, S., Kryshtopa, L., Bogatchuk, I., Prunko, I., Melnyk, V. (2017). Examining the effect of triboelectric phenomena on wear-friction properties of metal-polymeric frictional couples. Eastern-European Journal of Enterprise Technologies, 1 (5 (85)), 40–45. doi: 10.15587/1729-4061.2017.91615
6. Dykha, A., Kuzmenko, A., Babak, J. (2011). Contact mechanics and wear of lubricated tribosystem. Khmelnitsky: KhNU, 250.
7. Dykha, A. V., Kuzmenko, A. G. (2016). Distribution of friction tangential stresses in the Courtney-Pratt experiment under Bowden's theory. Journal of Friction and Wear, 37 (4), 315–319. doi: 10.3103/s1068366616040061
8. Sorokatyi, R. V., Dykha, A. V. (2015). Analysis of processes of tribodamages under the conditions of high-speed friction. Journal of Friction and Wear, 36 (5), 422–428. doi: 10.3103/s106836661505013x
9. Sherif, H. A., Almufadi, F. A. (2016). Identification of contact parameters from elastic-plastic impact of hard sphere and elastic half space. Wear, 368-369, 358–367. doi: 10.1016/j.wear.2016.10.006
10. Lewis, S. R., Lewis, R., Olofsson, U. (2011). An alternative method for the assessment of railhead traction. Wear, 271 (1-2), 62–70. doi: 10.1016/j.wear.2010.10.035
11. Lewis, S. R., Lewis, R., Richards, P., Buckley-Johnstone, L. E. (2014). Investigation of the isolation and frictional properties of hydrophobic products on the rail head, when used to combat low adhesion. Wear, 314 (1-2), 213–219. doi: 10.1016/j.wear.2013.11.024

DOI: 10.15587/1729-4061.2017.101282

DEVELOPMENT OF A DYNAMIC MODEL OF TRANSIENTS IN MECHANICAL SYSTEMS USING ARGUMENT-FUNCTIONS (p. 11-22)

Valery Chigirinsky
Zaporizhzhya National Technical
University, Zaporizhzhya, Ukraine
ORCID: http://orcid.org/0000-0002-5887-2747

Alexander Putnoki
Zaporizhzhya National Technical
University, Zaporizhzhya, Ukraine
ORCID: http://orcid.org/0000-0003-0729-1050

There are a number of applied problems in which it is necessary to take into account the dynamic component of the process or phenomenon including the fact that the load is applied not instantaneously but in time. For example, in continuous rolling, such combinations of mechanical systems appear in which action transfer from one rolling stand to another via the strip proceeds with some delay affecting transient processes and the strip gripping capability in the

adjacent stands of the continuous mill. The strip between the mill stands is in an elastic state. When the rolls start acting on it during the bite in the next stand, they transfer disturbance to the strip in a form of oscillations or in a form of a stationary action.

The aim of this research was to expand the application field of the obtained solutions to satisfy boundary and initial conditions formulated by applied production problems. The wave problem was considered as the process of propagation of the initial deviation and initial velocity.

On the basis of the method, the essence of which is the use of argument-functions, solution of dynamic linear and spatial problems of the elasticity theory was shown. In the course of the study, conditions for existence of new solutions for the wave problem, which are limited by the boundary conditions of various processes were shown. The initial differential equations and boundary conditions determine the type of differential equations for the argument-functions that close the solution. Argument-functions can be restricted by the Cauchy-Riemann relations and the corresponding differential invariants on the one hand and the differential relationships which result in that the argument-functions are the same for adjacent coordinate-time dependencies on the other hand. Besides, analytical dependences on the parameters entering into the d'Alembert formula were obtained.

Keywords: dynamic problem, wave equation, flat functions, adjacent stands, argument-functions, conditions for the existence of solutions.

References

1. Putnoki, A. Yu. (2015). Mathematical model of rolling dynamics when filling finishing train of wide-strip mill with strip. Metallurgical and Mining Industry, 11, 218–222.
2. Bronshteyn, I. M., Semendyayev, K. L. (1964). Spravochnik po matematike Moscow: Nauka, 608.
3. Sneddon, I. N., Berri, D. S.; Grigolyuk, E. I. (Ed.) (1961). Klassicheskaya teoriya uprugosti. Moscow, 219.
4. Mehtiev, M. F. (2008). Asimptoticheskiy analiz nekotoryih prostranstvennyih zadach teorii uprugosti dlya polyih tel. Baku, 320.
5. Krupoderov, A. V., Scherbakov, S. S. (2013). Reshenie nekotoryih dinamicheskih zadach teorii uprugosti metodom granichnyih elementov. Teoreticheskaya i prikladnaya mehanika, 28, 294–300.
6. Ermolenko, G. Yu. (2003). Reshenie dinamicheskoy zadachi anizotropnoy teorii uprugosti so smeshannyimi kraevyimi usloviyami. Vestn. Sam. gos. tehn. un-ta. Ser. Fiz.-mat. nauki, 86–88.
7. Sinekop, N. S., Lobanova, L. S., Parhomenko, L. A. (2015). Metod R-funktsiy v dinamicheskih zadachah teorii uprugosti. Kharkiv, 95.
8. Zakaryan, T. V. (2013). O sobstvennyih kolebaniyah ortotropnyih plastin v pervoy kraevoy zadachi teorii uprugosti pri nalichie vyazkogo soprotivleniya. Izv. NAN Armenii. Mehanika, 66 (3), 38–48.
9. Bagdaev, A. G., Vardanyan, A. V., Vardanyan, S. V. (2007). Reshenie nestatsionarnoy smeshannoy granichnoy zadachi teorii uprugosti dlya poluprostranstva. Izv. NAN Armenii. Mehanika, 60 (4), 23–37.
10. Kupradze, V. D., Burchuladze, T. V. (1975). Dinamicheskie zadachi teorii uprugosti i termouprugosti. Itogi nauki i tehn. Seriya "Sovremennyie problemyi matematiki", 7, 163–294.
11. Tikhonov, A. N., Samarskiy, A. A. (1966). Uravneniya matematicheskoy fiziki. Moscow: Nauka, 724.
12. Panovko, Ya. G. (1976). Osnovy prikladnoy teorii uprugikh kolebaniy i udara. Leningrad: Mashinostroenie, 320.
13. Babanov, I. M. (1968). Teoriya kolebaniy. Moscow: Nauka, 560.
14. Noritsin, I. A. (1977). Proyektirovaniye kuznechnykh i kholodnoshtampovochnykh tsekhov i zavodov. Moscow: Vycshaya shkola, 422.
15. Chigirinskiy, V. V. (2009). Metod resheniya zadach teorii plastichnosti s ispolzovaniyem garmonicheskikh funktsiy. Izv. vuzov. Chernaya metallurgiya, 5, 11–16.
16. Chigirinskiy, V. V., Kresanov, Yu. S., Kachan, A. Ya., Boguslaev, A. V., Legotkin, G. I., Slepyinin, A. Ya. et. al. (2014). Proizvodstvo tonkostennogo prokata spetsialnogo naznacheniya. Zaporozhe, 285.
17. Chigirinsky, V. V., Lenok, A. A., Echin, S. M. (2015). Determination of integral characteristics of stress state of the point during plastic deformation in conditions of volume loading. Metallurgical and Mining Industry, 11, 153–163.
18. Chigirinskiy, V. V., Sheyko, S. P., Plakhotnik, V. V. (2013). Novyye podkhody v reshenii dinamicheskikh zadach obrabotki metallov davleniyem. Visnik SevNTU, 137, 99–102.
19. Chigirinskiy, V. V., Putnoki, A. Yu. (2015). Vliyaniye dinamicheskogo nagruzheniya v smezhnykh kletyakh prokatnogo stana. Fundamentalnyye i prikladnyye problem tekhniki i tekhnologii, 4 (312), 21–26.
20. Targ, S. M. (1998). Kratkiy kurs teoreticheskoy mehaniki. Moscow: Vyschaya shkola, 411.

DOI: 10.15587/1729-4061.2017.101832

METHODS OF BALANCING OF AN AXISYMMETRIC FLEXIBLE ROTOR BY PASSIVE AUTO-BALANCERS (p. 22-27)

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

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

Kostyantyn Dumenko
Central Ukrainian National Technical University, Kropivnitskyi, Ukraine
ORCID: http://orcid.org/0000-0002-9718-6408

Vladimir Pirogov
Central Ukrainian National Technical University, Kropivnitskyi, Ukraine
ORCID: http://orcid.org/0000-0002-5843-4552

The conditions for the occurrence of auto-balancing when balancing a flexible axisymmetric rotor by any number of passive auto-balancers of any type are determined. The problem is actual for the high-speed rotors working at supercritical speeds (rotors of aircraft engines, gas turbine engines of power plants, etc.).

The empirical criterion for the occurrence of auto-balancing is applied. Transformations were carried out on the example of the flexible axisymmetric rotor of constant section on two rigid hinge supports. The findings are applicable to rotors with another type of fixing.

It is established that auto-balancing of the rotor by n passive auto-balancers located in different correction planes is possible only if the rotor speed exceeds the n-th critical speed. The number of auto-balancers can be arbitrary. Between the critical rotor speeds, additional critical speeds appear. Auto-balancing occurs whenever the rotor passes a critical speed and disappears whenever the rotor passes an additional critical speed.

If n auto-balancers are located in the n nodes of the rotor flexural (n+1)-th mode, the j·n-th additional critical rotor speed matches with the j(n+1)-th critical speed, /j=1, 2, 3,…/. When balancing the flexible rotor between the n-th and (n+1)-th critical speeds, such number and placement of auto-balancers are optimum. Auto-balancers at the same time balance the first n distributed modal unbalances and do not respond to the (n+1)-th ones.

The additional critical speeds are due to the installation of the auto-balancers on the rotor. Upon transition to them, the behavior of auto-balancers changes. At slightly lower rotor speeds, the auto-balancers reduce the rotor unbalance, and at slightly higher ones – increase it.

Keywords: flexible rotor, passive auto-balancer, auto-balancing, criterion for occurrence of auto-balancing, critical speeds of flexible rotor.

References

1. Shchepetilnikov, V. A. (Ed.) (1975). Osnovy balansirovochnoi tekhniki [Fundamentals of balancing technique]. Vol. 2. Uravnoveshivanie gibkih rotorov i balansirovochnoe oborudovanie. Moscow: Mashinostroenie, 679.
2. Ishida, Y., Yamamoto, T. (2012). Linear and Nonlinear Rotordynamics. Wiley-VCH, 474. doi: 10.1002/9783527651894
3. Filimonihin, G. B. (2004). Zrivnovazhennja i vibrozahyst rotoriv avtobalansyramy z tverdymy koryguval'nymy vantazhamy [Balancing and protection from vibrations of rotors by autobalancers with rigid corrective weights]. Kirovograd: KNTU, 352.
4. Filimonikhin, G., Filimonikhina, I., Dumenko, K., Lichuk, M. (2016). Empirical criterion for the occurrence of auto-balancing and its application for axisymmetric rotor with a fixed point and isotropic elastic support. Eastern-European Journal of Enterprise Technologies, 5 (7 (83)), 11–18. doi: 10.15587/1729-4061.2016.79970
5. Filimonikhin, G., Filimonikhina, I., Yakymenko, M., Yakimenko, S. (2017). Application of the empirical criterion for the occurrence of auto-balancing for axisymmetric rotor on two isotropic elastic supports. Eastern-European Journal of Enterprise Technologies, 2 (7 (86)), 51–58. doi: 10.15587/1729-4061.2017.96622
6. Sperling, L., Ryzhik, B., Duckstein, H. (2001). Two-plain automatic balancing. Machine Dynamics Problems, 25 (3/4), 139–152.
7. Sperling, L., Ryzhik, B., Duckstein, H. (2004). Single-Plain Auto-Balancing of Rigid Rotors. Technische Mechanik, 24 (1), 1–24.
8. Detinko, F. M. (1956). Ob ustoychivosti raboty avtobalansira dlya dinamicheskoy balansirovki [On the stability of work auto-balancer for dynamic balancing]. Proceedings of the Academy of Sciences of the USSR. Meh. and machine building, 4, 38–45.
9. DeSmidt, H. A. (2009). Imbalance Vibration Suppression of a Supercritical Shaft via an Automatic Balancing Device. Journal of Vibration and Acoustics, 131 (4), 041001. doi: 10.1115/1.3025834
10. Bykov, V. G., Melnikov, A. E. (2010). A mathematical model of a flexible rotor using the generalized Lagrangian coordinates. Vestnik of Saint-Petersburg State University. Series 1. Mathematics. Mechanics. Astronomy, 4, 110–118.
11. Bykov, V. G., Melnikov, A. E. (2011). Automatic balancing of the disk on flexible massive shaft. Vestnik of Saint-Petersburg State University. Series 1. Mathematics. Mechanics. Astronomy, 2, 116–126.
12. Ehyaei, J., Moghaddam, M. M. (2009). Dynamic response and stability analysis of an unbalanced flexible rotating shaft equipped with n automatic ball-balancers. Journal of Sound and Vibration, 321 (3-5), 554–571. doi: 10.1016/j.jsv.2008.10.019
13. Yu, H. H., Chung-Jen, L. (2015). Application of automatic balancers on a flexible-shaft rotor system. The 22nd International Congress on Sound and Vibration, ICSV22, 5, 3762–3770.
14. Majewski, T., Szwedowicz, D., Melo, M. A. M. (2015). Self-balancing system of the disk on an elastic shaft. Journal of Sound and Vibration, 359, 2–20. doi: 10.1016/j.jsv.2015.06.035
15. Goncharov, V., Filimonikhin, G., Dumenko, K., Lychuk, M. (2016). Studying the peculiarities of balancing of flexible double-support rotors by two passive automatic balancers placed near supports. Eastern-European Journal of Enterprise Technologies, 4 (7 (82)), 4–9. doi: 10.15587/1729-4061.2016.75115
16. Goncharov, V., Nevdakha, A., Nevdakha, Y., Gutsul, V. (2016). Research of stability and transition processes of the flexible double-support rotor with auto-balancers near support. Eastern-European Journal of Enterprise Technologies, 6 (7 (84)), 22–27. doi: 10.15587/1729-4061.2016.85461

DOI: 10.15587/1729-4061.2017.101315

NUMERICAL STUDY OF FLOW IN THE STAGE OF AN AXIAL COMPRESSOR WITH DIFFERENT TOPOLOGY OF COMPUTATIONAL GRID (p. 28-33)

Yuriy Tereshchenko
National Aviation University, Kyiv, Ukraine
ORCID: http://orcid.org/0000-0003-4367-3232

Ekaterina Doroshenko
National Aviation University, Kyiv, Ukraine
ORCID: http://orcid.org/0000-0001-6495-3263

Ivan Lastivka
National Aviation University, Kyiv, Ukraine
ORCID: http://orcid.org/0000-0001-5226-9819

Yuriy Tereshchenko
National Aviation University, Kyiv, Ukraine
ORCID: http://orcid.org/0000-0002-1908-0923

We conducted a series of calculations with the models of turbulent viscosity k–e, SST and three variants of three-dimensional unstructured computational grids. For each variant of the computational grid we calculated each of the two models of turbulent viscosity at axial velocity at input from 110 to 150 m/s. Comparison of results of numerical experiments with data of the physical experimental studies revealed that an error of the computational research is 0.3...8.6 %. Results of the study showed that at the first phase of calculation of the stage of an axial compressor one can recommend using the model of turbulent viscosity k–e and the coarse computational grid. To solve the problems on internal aerodynamics of compressors taking into account the flow in the near-border layer and aerodynamic trail, it is expedient to employ the model of turbulent viscosity SST and the fine adaptive grid.

Keywords: simulation of flow, computational grid, model of turbulent viscosity, stage of compressor, near-border layer.

References

1. Tereshhenko, Ju. M. (1987). Aerodinamicheskoe sovershenstvovanie lopatochnyh apparatov kompressorov. Moscow: Mashynostroenie, 168.

2. Brusilovskiy, I. V. (1984). Aerodinamika osevyh ventiliatorov. Moscow: Mashinostroenie, 240.
3. Pinto, R. N., Afzal, A., D'Souza, L. V., Ansari, Z., Mohammed Samee, A. D. (2016). Computational Fluid Dynamics in Turbomachinery: A Review of State of the Art. Archives of Computational Methods in Engineering. doi: 10.1007/s11831-016-9175-2
4. Naseri, A., Boroomand, M., Sammak, S. (2016). Numerical investigation of effect of inlet swirl and total-pressure distortion on performance and stability of an axial transonic compressor. Journal of Thermal Science, 25 (6), 501–510. doi: 10.1007/s11630-016-0891-6
5. Tereshhenko, Ju. M., Doroshenko, E. V., Abolhassan zade, Dzh. (2015). Flow simulation in compressor cascades at high angles of attack. Eastern-European Journal of Enterprise Technologies, 4 (8 (76)), 26–30. doi: 10.15587/1729-4061.2015.47206
6. Tereshhenko, Ju. M., Doroshenko, E. V., Abolhassan zade, Dzh. (2015). Influence research of profile chords ratio on aerodynamic characteristics of tandem compressor cascade. Eastern-European Journal of Enterprise Technologies, 5 (8 (77)), 9–13. doi: 10.15587/1729-4061.2015.50535
7. Song, P., Sun, J. (2015). Blade shape optimization for transonic axial flow fan. Journal of Mechanical Science and Technology, 29 (3), 931–938. doi: 10.1007/s12206-015-0207-x
8. Janke, C., Bestle, D., Becker, B. (2015). Compressor map computation based on 3D CFD analysis. CEAS Aeronautical Journal, 6 (4), 515–527. doi: 10.1007/s13272-015-0159-y
9. Yin, S., Jin, D., Gui, X., Zhu, F. (2010). Application and comparison of SST model in numerical simulation of the axial compressors. Journal of Thermal Science, 19 (4), 300–309. doi: 10.1007/s11630-010-0387-8
10. Liu, Y., Yan, H., Fang, L., Lu, L., Li, Q., Shao, L. (2016). Modified k-ω model using kinematic vorticity for corner separation in compressor cascades. Science China Technological Sciences, 59 (5), 795–806. doi: 10.1007/s11431-015-6005-y
11. Krivosheev, I. A., Chechulin, A. Ju., Hohlova, Ju. A. (2011). Choice model of turbulence in calculating loss of pressure in the flow of the gas turbine engine using software ANSYS CFX. Vestnik UGATU, 15 (2 (42)), 68–73.
12. Bykov, L. V., Molchanov, A. M., Shherbakov, M. A., Janyshev, D. S. (2015). Vychislitel'naya mehanika sploshnyh sred v zadachah aviacionnoy i kosmicheskoy tehniki. Moscow: LENAND, 668.
13. Menter, F. R. (1994). Two-equation eddy-viscosity turbulence models for engineering applications. AIAA Journal, 32 (8), 1598–1605. doi: 10.2514/3.12149
14. Jun, A. A. (2009). Teoriya i praktika modelirovaniya turbulentnyh techeniy. Moscow: Librokom, 274.
15. Svechnikov, V. S., Kirillov, A. B. (1958). Aerodinamicheskie harakteristiki stupeni osevogo kompressora. Moscow: CAGI, 94.
16. Boiko, A. V., Govorushhenko, Ju. N., Burlaka, M. V. (2012). Primenenie vychislitel'noi aerodinamiki k optimizacii lopatok turbomashin. Kharkiv: NTU «KhPI», 192.

DOI: 10.15587/1729-4061.2017.100835

COMPUTER SIMULATION OF HYDRAULIC FLOW IN A MIXING DEVICE WITH A DIAPHRAGM OF SPECIAL DESIGN INSTALLED IN IT (p. 33-39)

Andrey Shevchenko
Prodeko-Elk Sp.zo.o., Elk, Poland
ORCID: http://orcid.org/0000-0002-7332-5661

Tamara Shevchenko
O. M. Beketov National University of Urban Economy in Kharkiv, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-4513-6759

The results of computer simulation of hydrodynamic flow were presented using the FlowVision software package (Moscow, Russian Federation). This program has enabled creation of hydrodynamic flow models using three types of mixers: a mixer with the proposed diaphragm of special design, a pipe mixer and an orifice mixer. The complete information on behavior of the processes was obtained taking into account design and technological parameters of the abovementioned types of mixers. Computer simulation of flow in mixers of various types made it possible to substantially shorten time for conducting studies and confirm the results of field experiments presented earlier by the authors [11].

As a result of the analysis of the data obtained in the computer simulation of motion of the flow of waste water with the reagent solution, the following can be distinguished: when using different types of mixers, the best results of intensive flow mixing were obtained by using a mixer with a diaphragm of a special design and an orifice mixer. It is evidenced by the diagrams of distribution of pressure and velocities in these mixers. However, when using an orifice mixer, one can notice intensive mixing only at the center of the flow, and zones were noticeable at the walls of the pipeline in which there was practically no vortex formation and mixing respectively. In the pipe mixer, only a small region could be noticed in an immediate vicinity of the point of injection of the coagulant solution. Pressure and velocity vary in this region but these parameters change insignificantly in the main flow. The obtained hydrodynamic models indicate that the proposed diaphragm of a special design provides more efficient mixing of wastewater with the reagent. Models for pipe and orifice mixers have shown worse results. The proposed diaphragm enabled mixing of wastewater with the reagent as fully and quickly as possible.

Keywords: static mixer, computer simulation, pressure and velocity distribution diagram, turbulent dissipation.

References

1. Mixing of coagulants with water. Pology chemical plant "Coagulant". Available at: http://coagulant-producer.com/
2. Shevchenko, T. A., Shevchenko, A. A. (2015). The Intensification of the flotation unit in a wastewater treatment of dairy industry. Visnyk Odes'koyi derzhavnoyi akademiyi budivnytstva ta arkhitektury, 59, 150–155.
3. Babatola, J. O., Oladepo, K. T., Lukman, S., Olarinoye, N. O., Oke, I. A. (2011). Failure Analysis of a Dissolved Air Flotation Treatment Plant in a Dairy Industry. Journal of Failure Analysis and Prevention, 11 (2), 110–122. doi: 10.1007/s11668-010-9430-z
4. Wastewater treatment in the dairy processing industry – recovering energy using anaerobic technology. Available at: http://envirochemie.com/cms/upload/downloads-en/fachbeitraege/Whitepaper_Wastewater_treatment_in_the_dairy_processing_industry_.pdf
5. Boruszko, D., Dabrowski, W. (2014). Research on the Effectiveness of the Flotation Process and Properties of Flotation Sludge from Dairy Wastewater Pretreatment. Inzynieria i Ochrona Srodowiska, 17 (2), 269–280.
6. Alekseev, K. A., Muhametzyanova, A. G., Klinov, A. V., Farahov, M. I., Kirichenko, S. M. (2013). Experimental study of the hydraulic char-

acteristics of flow static mixer Packed. Vestnik Kazanskogo tekhnologicheskogo universiteta, 16 (7), 212–216.

7. Mixing and Reaction Technology. Pace Setting Technology. Available at: http://www.sulzer.com/lv/-/media/Documents/ProductsAndServices/Mixpac_Cartridges_Applications_Static_Mixers/Static_Mixers/Brochures/Mixing_and_Reaction_Technology_e_23270640.pdf
8. Laptev, A. G., Farakhov, M. I., Todorovska, O. G. (2012). The Efficiency of turbulent mixing of media in a Packed flow-through mixers. Electronic scientific journal "Oil and gas business", 4, 387–408.
9. Tishin, O. A., Kharitonov, V. N. (2012). Analysis of the mixer in the "FlowVisison". News of Volgograd state technical University, 1 (5), 80–83.
10. FlowVision. User's manual (Version 3.09.0.) (2015). Moscow: LLC "TESIS", 1294.
11. Shevchenko, T. A., Shevchenko, A. A. (2016). Experimental investigation of intensification of the process of dissolved-air flotation in wastewater treatment of milk processing enterprises. Eastern-European Journal of Enterprise Technologies, 1 (6 (79)), 4–12. doi: 10.15587/1729-4061.2016.60121
12. Shevchenko, A. A. et. al. (2014). Pat. No. 147134. Device for coagulation waste liquid. declareted: 10.07.2014; published: 26.09.2014.

DOI: 10.15587/1729-4061.2017.101298

FORMALIZATION OF DESIGN FOR PHYSICAL MODEL OF THE AZIMUTH THRUSTER WITH TWO DEGREES OF FREEDOM BY COMPUTATIONAL FLUID DYNAMICS METHODS (p. 40-49)

Vitalii Budashko
National University
«Odessa Maritime Academy», Odessa, Ukraine
ORCID: http://orcid.org/0000-0003-4873-5236

Based on theoretical and practical studies into the causes of losses of propellers, caused by the axial inflows, employing the methods of computational fluid dynamics, we calculated the geometry of physical model of the thrusters with two degrees of freedom. We specified the required physical conditions of implementation, formalized geometric parameters of the model, assigned the initial and boundary conditions of differential equations that describe behavior of propeller flows in the recirculation zones. The coefficients are calculated that take into account the existence of degradation effects.

The use of methods of computational fluid dynamics is necessary to account for the losses of propellers caused by the axial water inflows that are dependent on the degradation effects, which will contribute to reducing the propeller thrust and torque.

As the result of the studies, we received the Reynolds and Froude numbers for the zero-velocity model of the ship: R_n=4.405×106; F_r=3.124. Components of the axial and tangential forces of the radial distribution of steering propellers thrusts are refined within the limits of 2.7–5.1 %. The largest deviation of similarity coefficients is in the region of 85–100 % of the rated propeller thrust. We obtained dependences of adjustment factors that affect the components of thrusts and torques proportional to the radius of propeller of the model and the actual steering propeller, related to the original geometry. The value of corrective factors depending on the propeller flow direction relative to the plane of motion of the ship is within the few hundredths of the percent. We systematized and compiled in the table the list of parameters (factors) according to the operating mode of the ship, which are required to solve the basic equations in the formalization of physical models of thrusters.

The designed principles of formalization of the physical models of thrusters could be employed in the process of selection and improvement of design of combined propulsive complex and adjustment of selected regulators of components of the ship power plant.

Keywords: ship steering propeller, degradation effect, formalization of the physical model, computational fluid dynamics.

References

1. Wang, F., Lv, M., Xu, F. (2016). Design and implementation of a triple-redundant dynamic positioning control system for deepwater drilling rigs. Applied Ocean Research, 57, 140–151. doi: 10.1016/j.apor.2016.03.007
2. Ryu, M., Jeon, D. S., Kim, Y. (2015). Prediction and improvement of the solid particles transfer rate for the bulk handing system design of offshore drilling vessels. International Journal of Naval Architecture and Ocean Engineering, 7 (6), 964–978. doi: 10.1515/ijnaoe-2015-0067
3. Azimuthing Electric Propulsion Drive. Available at: http://www04.abb.com/global/seitp/seitp202.nsf/0/589ea2a5cd61753ec12570c9002ab1d1/$file/AzipodNew.pdf
4. Azipod Propulsion System. Available at: http://www.dieselduck.info/machine/02%20propulsion/2006%20Introduction%20to%20Azipod%20Propulsion.pdf
5. Kobylinski, L. (2013). Problems of Handling Ships Equipped with Azipod Propulsion Systems. Prace naukowe politechniki warszawskiej, 95, 232–245. Available at: https://pbn.nauka.gov.pl/polindex-webapp/browse/article/article-f315dfd7-df06-463e-8de7-b553f8c232db
6. Cozijn, H., Hallmann, R., Koop, A. (2010). Analysis of the velocities in the wake of an azimuthing thruster, using PIV measurements and CFD calculations. Dynamic positioning conference: thrusters session. Available at: http://www.refresco.org/wp-content/uploads/2015/05/2010-MTS-DP-Cozijn-Hallmann-Koop.pdf
7. Final report on the investigation of the Macondo well blowout (2011). Deepwater horizon study group. Available at: http://ccrm.berkeley.edu/pdfs_papers/bea_pdfs/dhsgfinalreport-march2011-tag.pdf
8. Palmer, A., Hearn, G. E., Stevenson, P. (2008). Modelling Tunnel Thrusters for Autonomous Underwater Vehicles. IFAC Proceedings Volumes, 41 (1), 91–96. doi: 10.3182/20080408-3-ie-4914.00017
9. Taskar, B., Yum, K. K., Steen, S., Pedersen, E. (2016). The effect of waves on engine-propeller dynamics and propulsion performance of ships. Ocean Engineering, 122, 262–277. doi: 10.1016/j.oceaneng.2016.06.034
10. Jian, L., Xiwen, L., Zuti, Z., Xiaohui, L., Yuquan, Z. (2016). Numerical investigation into effects on momentum thrust by nozzle's geometric parameters in water jet propulsion system of autonomous underwater vehicles. Ocean Engineering, 123, 327–345. doi: 10.1016/j.oceaneng.2016.07.041
11. Sordalen, O. J. (1997). Optimal thrust allocation for marine vessels. Control Engineering Practice, 5 (9), 1223–1231. doi: 10.1016/s0967-0661(97)84361-4

12. Arditti, F., Tannuri, E. A. (2012). Experimental Analysis of a Thrust Allocation Algorithm for DP Systems Considering the Interference between Thrusters and Thruster-Hull. IFAC Proceedings Volumes, 45 (27), 43–48. doi: 10.3182/20120919-3-it-2046.00008
13. Budashko, V., Nikolskyi, V., Onishchenko, O., Khniunin, S. (2015). Physical model of degradation effect by interaction azimuthal flow with hull of ship. Proceeding Book of International Conference on Engine Room Simulators (ICERS12). Istanbul: Istanbul Technical University, Maritime Faculty, 49–53.
14. Nikolskyi, V., Budashko, V., Khniunin, S. (2015). The monitoring system of the Coanda effect for the tension-leg platform's. Proceeding Book of International Conference on Engine Room Simulators (ICERS12). Istanbul: Istanbul Technical University, Maritime Faculty, 45–49.
15. Mauro, F., Nabergoj, R. (2016). Advantages and disadvantages of thruster allocation procedures in preliminary dynamic positioning predictions. Ocean Engineering, 123, 96–102. doi: 10.1016/j.oceaneng.2016.06.045
16. Xiao, H., Wu, J.-L., Wang, J.-X., Sun, R., Roy, C. J. (2016). Quantifying and reducing model-form uncertainties in Reynolds-averaged Navier-Stokes simulations: A data-driven, physics-informed Bayesian approach. Journal of Computational Physics, 324, 115–136. doi: 10.1016/j.jcp.2016.07.038
17. Mishra, C., Samantaray, A. K., Chakraborty, G. (2016). Rolling element bearing defect diagnosis under variable speed operation through angle synchronous averaging of wavelet de-noised estimate. Mechanical Systems and Signal Processing, 72-73, 206–222. doi: 10.1016/j.ymssp.2015.10.019
18. Saha, N., Panda, S. (2016). Speed control with torque ripple reduction of switched reluctance motor by Hybrid Many Optimizing Liaison Gravitational Search technique. Engineering Science and Technology, an International Journal. doi: 10.1016/j.jestch.2016.11.018
19. Maciel, P., Koop, A., Vaz, G. (2013). Modelling Thruster-Hull Interaction with CFD. OMAE ASME 32nd International Conference on Ocean, Offshore and Arctic Engineering. France. Available at: http://www.marin.nl/web/Publications/Publication-items/Modelling-ThrusterHull-Interaction-with-CFD.htm
20. Thiebot, J., Guillou, S., Nguyen, V. T. (2016). Modelling the effect of large arrays of tidal turbines with depth-averaged Actuator Disks. Ocean Engineering, 126, 265–275. doi: 10.1016/j.oceaneng.2016.09.021
21. Budashko, V. V., Onishchenko, O. A. (2014). Udoskonalennja systemy upravlinnja pidruljujuchym prystrojem kombinovanogo propul'syvnogo kompleksu [Improving management system combined thruster propulsion systems]. Bulletin of NTU "KhPI", 38 (1081), 45–51. Available at: http://repository.kpi.kharkov.ua/bitstream/KhPI-Press/13378/1/vestnik_HPI_2014_38_Budashko_Udoskonalennia.pdf
22. Budashko, V. V. (2015). Implementarnyiy podhod pri modelirovanii energeticheskih protsessov dinamicheski pozitsioniruyuschego sudna [Implementation approaches during simulation processes for a dynamically positioned ship]. Electrical engineering & electromechanics, 6, 14–19.
23. Boiko, A. A., Budashko, V. V., Yushkov, E. A., Boiko, N. A. (2016). Synthesis and research of automatic balancing system of voltage converter fed induction motor currents. Eastern-European Journal of Enterprise Technologies, 1 (2 (79)), 22–34. doi: 10.15587/1729-4061.2016.60544
24. Budashko, V. V., Onishchenko, O. A., Yushkov, E. A. (2014). Fizicheskoe modelirovanie mnogofunktsional'nogo propul'sivnogo kompleksa [Physical modeling of multi-propulsion complex]. Zbirnyk naukovyh prac' Vijs'kovoi' akademii' (m. Odesa). Tehnichni nauky, 2, 88–92. Available at: http://zbirnyk.vaodessa.org.ua/images/zbirnyk_2/13.PDF
25. Budashko, V. V., Nikolskyi, V. V., Khniunin, S. H. (2015). Pat. No. 100819 UA. Sudova systema monitorynhu dlya poperedzhennya effektu Koanda [Ship monitoring system for the prevention of Coanda effect]. No. u201501854; declareted: 02.03.2015; published: 10.08.2015, Bul. No. 15. Available at: http://base.uipv.org/searchINV/search.php?action=viewdetails&IdClaim=215069
26. Budashko, V. V., Yushkov, E. A. (2016). Pat. No. 108074 UA. Systema impul sno-fazovoho upravlinnya elektropryvodom sudnovoyi hvynto-kermovoyi ustanovky [The pulse-phase control system of electric ship propeller-steering plant]. No. u201601510; declareted: 18.02.2016; published: 24.06.2016, Bul. No. 12. Available at: http://base.uipv.org/searchINV/search.php?action=viewdetails&IdClaim=224863
27. Khnyunin, S. H., Nikolskyi, V. V., Budashko, V. V. (2015). Pat. No. 107006 UA. Sudova systema monitorynhu dlya poperedzhennya effektu Koanda [Ship system for monitoring for preventing the Coanda effect]. No. u201512962; declareted: 28.12.2015; published: 10.05.2016, Bul. No. 9. Available at: http://base.uipv.org/searchINV/search.php?action=viewdetails&IdClaim=223437
28. Budashko, V., Nikolskyi, V., Onishchenko, O., Khniunin, S. (2016). Decision support system's concept for design of combined propulsion complexes. Eastern-European Journal of Enterprise Technologies, 3 (8 (81)), 10–21. doi: 10.15587/1729-4061.2016.72543

DOI: 10.15587/1729-4061.2017.102241

PARAMETER OPTIMIZATION OF THE CENTRIFUGAL JUICER WITH THE BALL AUTO-BALANCER UNDER THE IMPULSE CHANGE OF AN UNBALANCE BY 3D MODELING (p. 50-58)

Valery Goncharov
Central Ukrainian National
Technical University, Kropivnitskyi, Ukraine
ORCID: http://orcid.org/0000-0003-4652-8604

Kostyantyn Dumenko
Central Ukrainian National
Technical University, Kropivnitskyi, Ukraine
ORCID: http://orcid.org/0000-0002-9718-6408

Andrey Nevdakha
Central Ukrainian National
Technical University, Kropivnitskyi, Ukraine
ORCID: http://orcid.org/0000-0002-0849-9331

Vladimir Pirogov
Central Ukrainian National
Technical University, KropivnitskyiУ, Ukraine
ORCID: http://orcid.org/0000-0002-5843-4552

The optimization of the parameters of the centrifugal juicer with the ball auto-balancer under the impulse change of the sieve unbalance at cruising velocity is conducted by 3D modeling. The dependence of the duration of the transition processes on the main parameters of the juicer and the auto-balancer is studied.

Using the example of a two-ball auto-balancer, the impulse changes of an unbalance, which are the most unfavorable for the duration of transition processes, are found: the turn of the unbalance vector around the rotation axis of the rotor by 90° or 180°. In this, the balls pass the longest distance along the running track.

The following is established.

1. The proposed in previous works methods of optimizing the parameters of machines with an auto-balancer for minimization of the duration of transition processes are also efficient under the impulse change of an unbalance at cruising velocity.

2. The previously obtained results are confirmed, namely:

a) the increase of the number of the balls in the auto-balancer leads to the decrease of the duration of transition process; this is explained by the fact, that:

– when there are more than two balls in the auto-balancer, the multi-parameter family of the steady motions appears in the rotor machine;

– under the change of an unbalance, the balls make the transition between the two nearest steady motions;

b) the decrease of the running track radius leads to the decrease of the duration of transition processes; this is due to the fact, that the running track becomes more filled and the balls need to move less between auto-balancing positions;

c) the dependence of the optimal values of the parameters of the centrifugal juicer and the auto-balancer on the magnitude of an unbalance is revealed. The dependence is significant only for the two-ball auto-balancer and weakens with the increase of the number of the balls in the auto-balancer;

d) the use of the two-ball auto-balancer, both in practice and for theoretical and experimental studies of the duration of transition processes in auto-balancing of machines, is inexpedient.

3. It is established that at the centrifugal juicer run-up with the fixed unbalance and under the impulse change of its unbalance at cruising velocity:

– the trends in the influence of the running track radius of an auto-balancer and the number of the balls on the duration of transition processes are identical;

– the optimal values of the main parameters of the auto-balancer and the centrifugal juicer coincide, except for the coefficient of viscous resistance forces of the relative motion of the balls;

– the optimal values of the coefficient of viscous resistance forces of the relative motion of the balls at run-up are less than the corresponding values under the impulse change of an unbalance by 50 %.

Keywords: unbalance, auto-balancer, 3D modeling, impulse change of an unbalance, transition processes, centrifugal juicer.

Refrences

1. Thearle, E. L. (1950). Automatic dynamic balancers Part 2 – Ring, pendulum and ball balancers. Machine Design, 22 (10), 103–106.
2. Gusarov, A. (2002). Avtobalansirujushhie ustrojstva prjamogo dejstvija [Auto-balancers direct action devices]. Moscow: Nauka, 119.
3. Filimonikhin, G. (2004). Zrivnovazhennya i vibrozakhist rotoriv avtobalansiramy z tverdimi koriguvalnimi vantazhami [Balancing and protection from vibrations of rotors by autobalancers with rigid corrective weights]. Kirovohrad: KNTU, 352.
4. Filimonikhina, I. I., Filimonikhin, G. B. (2007). Conditions for balancing a rotating body in an isolated system with automatic balancers. International Applied Mechanics, 43 (11), 1276–1282. doi: 10.1007/s10778-007-0132-5
5. Filimonikhin, G., Filimonikhina, I., Dumenko, K., Lichuk, M. (2016). Empirical criterion for the occurrence of auto-balancing and its application for axisymmetric rotor with a fixed point and isotropic elastic support. Eastern-European Journal of Enterprise Technologies, 5 (7 (83)), 11–18. doi: 10.15587/1729-4061.2016.79970
6. Filimonikhin, G., Filimonikhina, I., Yakymenko, M., Yakimenko, S. (2017). Application of the empirical criterion for the occurrence of auto-balancing for axisymmetric rotor on two isotropic elastic supports. Eastern-European Journal of Enterprise Technologies, 2 (7 (86)), 51–58. doi: 10.15587/1729-4061.2017.96622
7. Filimonikhin, G. B., Olijnichenko, L. S. (2015). Investigation of the possibility of balancing aerodynamic imbalance of the impeller of the axial fan by correction of masses. Eastern-European Journal of Enterprise Technologies, 5 (7 (77)), 30–35. doi: 10.15587/1729-4061.2015.51195
8. Nesterenko, V. (1985). Avtomaticheskaya balansirovka rotorov priborov i mashin so mnogimi stepenyami svobody [Automatic rotor balancing devices and machines with many degrees of freedom]. Tomsk: Izd-vo Tomsk. un-ta, 84.
9. Sperling, L., Ryzhik, B., Duckstein, H. (2004). Single-Plain Auto-Balancing of Rigid Rotors. Technische Mechanik, 24 (1), 1–24.
10. Sperling, L., Ryzhik, B., Duckstein, H. (2001). Two-plain automatic balancing. Machine Dynamics Problems, 25 (3/4), 139–152.
11. Rodrigues, D. J., Champneys, A. R., Friswell, M. I., Wilson, R. E. (2011). Two-plane automatic balancing: A symmetry breaking analysis. International Journal of Non-Linear Mechanics, 46 (9), 1139–1154. doi: 10.1016/j.ijnonlinmec.2011.04.033
12. Filimonikhin, G., Goncharov, V. (2014). Uravnoveshivanie avtobalansirom rotora v uprugo-vyazko zakreplennom korpuse s nepodvizhnoy tochkoy [Balancing auto balancer rotor in visco-elastic body fixed to a fixed point]. Bulletin of the Tomsk Polytechnic University, 325 (2), 41–49.
13. Gorbenko, A. (2015). Mass-Inertial Characteristics and Dimensionless Equations of Two-bearing Rotor Motion with Auto-balancer in Terms of Compensating Body Mass. Science and Education of the Bauman MSTU, 12, 266–294. doi: 10.7463/1215.0827773
14. Detinko, F. (1956). Ob ustoychivosti raboty avtobalansira dlya dinamicheskoy balansirovki [On the stability of work auto-balancer for dynamic balancing]. Proceedings of the Academy of Sciences of the USSR. Meh. and machine building, 4, 38–45.
15. Hsieh, H.-Y., Lu, C.-J. (2015). Application of automatic balancers on a flexible-shaft rotor system. The 22nd International Congress on Sound and Vibration.
16. Majewski, T., Szwedowicz, D., Melo, M. A. M. (2015). Self-balancing system of the disk on an elastic shaft. Journal of Sound and Vibration, 359, 2–20. doi: 10.1016/j.jsv.2015.06.035
17. Goncharov, V., Filimonikhin, G., Dumenko, K., Lychuk, M. (2016). Studying the peculiarities of balancing of flexible double-support rotors by two passive automatic balancers placed near supports. Eastern-European Journal of Enterprise Technologies, 4 (7 (82)), 4–9. doi: 10.15587/1729-4061.2016.75115
18. Goncharov, V., Nevdakha, A., Nevdakha, Y., Gutsul, V. (2016). Research of stability and transition processes of the flexible double-support rotor with auto-balancers near support. Eastern-European Journal of Enterprise Technologies, 6 (7 (84)), 22–27. doi: 10.15587/1729-4061.2016.85461
19. Tadeusz, M. (1988). Position error occurrence in self balancers used on rigid rotors of rotating machinery. Mechanism and Machine Theory, 23 (1), 71–78. doi: 10.1016/0094-114x(88)90011-0
20. Yang, Q., Ong, E.-H., Sun, J., Guo, G., Lim, S.-P. (2005). Study on the influence of friction in an automatic ball balancing system. Journal of Sound and Vibration, 285 (1-2), 73–99. doi: 10.1016/j.jsv.2004.08.009

21. Sung, C. K., Chan, T. C., Chao, C. P., Lu, C. H. (2013). Influence of external excitations on ball positioning of an automatic balancer. Mechanism and Machine Theory, 69, 115–126. doi: 10.1016/j.mechmachtheory.2013.05.009
22. Haidar, A. M., Palacios, J. L. (2016). A general model for passive balancing of supercritical shafts with experimental validation of friction and collision effects. Journal of Sound and Vibration, 384, 273–293. doi: 10.1016/j.jsv.2016.08.023
23. Goncharov, V., Filimonikhin, G., Nevdakha, A., Pirogov, V. (2017). An increase of the balancing capacity of ball or roller-type auto-balancers with reduction of time of achieving auto-balancing. Eastern-European Journal of Enterprise Technologies, 1 (7 (85)), 15–24. doi: 10.15587/1729-4061.2017.92834
24. Filimonikhin, G. B., Goncharov, V. V. (2013). Pat. No. 107022 UA. Elektrychna tsentryfuzhna napivavtomatychna sokovyzhymalka [Electric centrifugal juicer semiautomatic]. IPC G01M 1/32. No. a201301212; declareted: 01.02.2013; published: 10.11.2014, Bul. No. 21.
25. Goncharov, V., Filimonikhin, G. (2014). Parameter optimization of 3D models of centrifugal juicer with auto-balancer by minimization of steady vibroacceleration. Eastern-European Journal of Enterprise Technologies, 1 (7 (67)), 9–14. doi: 10.15587/1729-4061.2014.20678
26. Goncharov, V., Filimonikhin, G. (2014). Parameters optimization of centrifugal juicer with auto-balancer by minimization of time of autobalancing occurred. Eastern-European Journal of Enterprise Technologies, 2 (7 (68)), 28–32. doi: 10.15587/1729-4061.2014.23317
27. Olijnichenko, L., Filimonikhin, G. (2014). Optimization of parameters of autobalancers for dynamic balancing of impeller of axial fans by 3D modeling. Eastern-European Journal of Enterprise Technologies, 6 (7 (72)), 12–17. doi: 10.15587/1729-4061.2014.30498
28. Filimonikhin, G., Olijnichenko, L. (2011). Eksperymentalne vyznachennya efeknyvnosti dynamichnoho zrivnovazhennya kulevymy avtobalansyramy krylchatky ocevoho ventylatora [Experimental determination of the efficiency of dynamic balancing by ball-type auto-balancers of the impeller of axial fan]. Automation products. Machine build processes and instrument, 45, 496–502.
29. Olijnichenko, L., Goncharov, V., Sidei, V., Horpynchenko, O. (2017). Experimental study of the process of the static and dynamic balancing of the axial fan impeller by ball auto-balancers. Eastern-European Journal of Enterprise Technologies, 2 (1 (86)), 42–50. doi: 10.15587/1729-4061.2017.96374

DOI: 10.15587/1729-4061.2017.101335

ANALYTICAL METHOD OF EXAMINING THE CURVILINEAR MOTION OF A FOUR-WHEELED VEHICLE (p. 59-65)

Victor Melnik
Kharkiv Petro Vasilenko National Technical University of Agriculture, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-1176-2831

Mikhail Dovzhik
Sumy National Agrarian University, Sumy, Ukraine
ORCID: http://orcid.org/0000-0002-1627-4888

Boris Tatyanchenko
Sumy National Agrarian University, Sumy, Ukraine
ORCID: http://orcid.org/0000-0001-8455-8244

Oleksandr Solarov
Sumy National Agrarian University, Sumy, Ukraine
ORCID: http://orcid.org/0000-0002-1485-0685

Yulia Sirenko
Sumy National Agrarian University, Sumy, Ukraine
ORCID: http://orcid.org/0000-0003-1818-3653

We obtained equations for the curvilinear trajectory of a four-wheeled vehicle in the parametric form of a function of turning angle of the machine frame. The equations are suitable for the sections of entering a turn and exiting a turn. The proposed equations make it possible to build the trajectories taking into account the intensity of turning the front steered wheels. For this purpose, the course angle is represented as a function of the turning angle of the body of a machine. For example, in the case of a linear dependence, the proportionality factor (coefficient of intensity of change in the course angle, predetermined by the rotation speed of steered wheels) depends on the turning angle of a steering wheel. The solution was found based on the projections of velocity of the center of mass of a machine onto the inertial coordinate axes. In this case, the integrand functions are represented through a single variable – turning angle of the machine frame. For this purpose, we employed a special substitution, which replaces the differential of time with the differential of turning angle of the machine frame. Following the decomposition of integrand functions into the Maclaurin series, the integration becomes possible. We also found the equation of motion along a circular trajectory at fixed position of a steering wheel. Along with the equations for entering a turn and exiting a turn, they allow us to build complex trajectories of u-turns in a unified coordinate system. For the conjugation of separate sections of the trajectory, we applied formulas of change in the coordinates at parallel carry and turn of the coordinate axes. The coordinates of points along the trajectory can be calculated by using the software tools.

The impact of the phenomenon of wheels slip under the action of lateral forces on the trajectory of curvilinear motion is accounted for by introducing to the equations the intensity coefficients that represent dependence of the course angle, caused by the slip, on the turning angle of the machine frame.

Keywords: four-wheeled vehicle, curvilinear motion, equation of trajectory, course angle, lateral slip.

References

1. Kalinin, E. I. Equation of motion of a hinged arable unit. Available at: http://www.rusnauka.com/16_NPRT_2009/Agricole/47638.doc.htm
2. Emelianov, A. M., Shchitov, S. V., Frolov, G. N. (2007). Mathematical modeling of the investigation of curvilinear motion of MTZ-82 tractor with twin wheels. Dal'nevostochnyi agrarnyi vestnik, 1, 101–109.
3. Vysotsky, M. S., Dubovik, D. A. (2008). Mathematical modeling of the curvilinear motion of wheeled vehicles. Bulletin of the Belarusian-Russian University, 2, 6–15.
4. Gorelov, V. A., Tropin, S. L. (2011). A mathematical model of the curvilinear motion of a road train on a non-deformable support base. Journal of Automotive Engineers, 5, 18–22.
5. Song, M.-Z., Kang, S.-W., Chung, S.-O., Kim, K.-D., Chae, Y.-S., Lee, D.-H. et. al. (2013). Development of Path Planning Algorithm for an Autonomous Mower Tractor. IFAC Proceedings Volumes, 46 (18), 154–158. doi: 10.3182/20130828-2-sf-3019.00022

6. Zhang, C., Yang, L., Noguchi, N. (2014). Development of a Human-driven tractor following a Robot System. IFAC Proceedings Volumes, 47 (3), 11559–11564. doi: 10.3182/20140824-6-za-1003.00751
7. Takai, R., Yang, L., Noguchi, N. (2013). Development of Crawler-Type Robot Tractor Based on GNSS and IMU. IFAC Proceedings Volumes, 46 (4), 95–98. doi: 10.3182/20130327-3-jp-3017.00024
8. Gomez-Gil, J., Alonso-Garcia, S., Gomez-Gil, F. J., Stombaugh, T. (2011). A Simple Method to Improve Autonomous GPS Positioning for Tractors. Sensors, 11 (12), 5630–5644. doi: 10.3390/s110605630
9. Sutisna, S. P., Subrata, I. D. M., Agus Setiawan, R. P. (2015). Sistem Pengendali Kemudi Traktor Otomatis Empat Roda Pada Pengujian Lintasan Lurus (Tracking Control System of Autonomous Four Wheel Tractor on Straight Path). Jurnal Agritech, 35 (01), 106. doi: 10.22146/agritech.9425
10. Garcia-Ramos, F. J., Vidal, M., Bone, A., Serreta, A. (2011). Methodology for the Regulation of Boom Sprayers Operating in Circular Trajectories. Sensors, 11 (12), 4295–4311. doi: 10.3390/s110404295
11. D'Antonio, P., D'Antonio, C., Evangelista, C., Doddato, V. (2013). Satellite guidance systems in agriculture: experimental comparison between EZ-Steer/RTK and AUTOPILOT/EGNOS. Journal of Agricultural Engineering, 44 (2s). doi: 10.4081/jae.2013.s2.e34
12. Melnik, V. I., Dovzhik, M. Ya., Tat'yanchenko, B. Ya., Solarov, O. O., Sirenko, Yu. V. (2016). The equation of curvilinear motion of the speed wheel tractor. Visnik Sumy National Agrarian University, 10/2 (30), 7–15.