MECHANICAL ENGINEERING TECHNOLOGY

DOI: 10.15587/2706-5448.2025.345022

DEVELOPMENT OF SPECIAL COLD SPRAY NOZZLE FOR INTERNAL SURFACE COATING DEPOSITION

pages 6–11

Oleksandr Shorinov, *PhD, Associate Professor, Department of Aviation Engine Manufacturing Technology, National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine, ORCID: https://orcid.org/0000-0002-5057-6679*

Andrii Volkov, *Senior Lecturer, Department of Aviation Engine Manufacturing Technology, National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine, ORCID: https://orcid.org/0000-0002-5899-1252*

Nina Savchenko, *PhD, Associate Professor, Head of Department of Higher Mathematics and Systems Analysis, National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine, e-mail: n.savchenko@khai.edu, ORCID: https://orcid.org/0000-0001-8144-9368*

Serhii Markovych, *PhD, Associate Professor, Independent Researcher, Kharkiv, Ukraine, ORCID: https://orcid.org/0000-0001-8321-2786*

Kostiantyn Danko, *PhD, Department Marketing and Scientific and Technical Information, Zaporizhzhia Machine-Building Design Bureau Progress Joint Stock Company named after Academician O. H. Ivchenko, Zaporizhzhia, Ukraine, ORCID: https://orcid.org/0000-0003-0251-7508*

Roman Ipatov, *Head of Laboratory, Department of Aviation Engine Manufacturing Technology, National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine, ORCID: https://orcid.org/0009-0007-3620-7897*

Increasing the service life of parts by forming protective and restorative coatings through cold spraying (CS) is a tough scientific and technical challenge. The object of the study is the process of accelerating powder particles in a supersonic rotating nozzle for CS. For CS, it is difficult, and sometimes even impossible, to form coatings on internal and hard-to-reach surfaces. In the practice of using the technology, this is considered one of the most problematic places, which limits the capabilities of the technology.

This paper focused on improving the CS process by developing a new supersonic rotating nozzle for coating deposition on internal and hard-to-reach surfaces of parts, establishing the regularities of the trajectory of motion and acceleration of powder particles in it. During the study, classical methods of computational gas dynamics were used, including methods for investigating two-phase flows. Experimental verification of the modeling results was performed by the pneumatic method of determining the Mach number using a Pitot-Prandtl tube. Numerical modeling of CS processes was performed for two designed rotating nozzles – two-channel and three-channel. The values of the maximum velocity of aluminum powder particles with a diameter of 10 μm at an air stagnation pressure of 4.0 MPa and stagnation temperature of 550°C were obtained: 558 m/s for the two-channel nozzle, and 585 m/s for the three-channel one, which is sufficient for adhesion of particles to the substrate. A three-channel nozzle was chosen for manufacturing and experimental testing. The difference between the experimental and calculated values of the Mach number at the nozzle outlet did not exceed 10%. The presence of two additional nozzles, located in the main channel and directed at an angle to the main flow direction, ensures the rotation of the flow with particles from the initial direction at an angle of approximately 75 degrees, which satisfies the requirements for forming CS coatings.

Keywords: coating, nozzle geometry, powder, optimization, CFD modeling, part recovery.

References

1. Meng, F., Zhou, Y., Zhang, H., Wang, Z., Liu, D., Cao, S. et al. (2025). Development and Research Status of Wear-Resistant Coatings on Copper and Its Alloys: Review. *Crystals, 15 (3),* 204. https://doi.org/10.3390/cryst15030204
2. Zhang, Z., Tarelnyk, V., Konoplianchenko, I., Guanjun, L., Xin, D., Yao, J. (2023). Characterization of Tin Bronze Substrates Coated by Ag + B83 through Electro-Spark Deposition Method. *Surface Engineering and Applied Electrochemistry, 59 (2),* 220–230. https://doi.org/10.3103/s1068375523020187
3. Dolmatov, A. I., Dan'ko, K. A., Neveshkin, Yu. A. (2016). Modelling of Distribution of Particles in a Two-Phase Flow of Detonation – Plasma Device. *Metallofizika i Noveishie Tekhnologii, 36 (11),* 1533–1546. https://doi.org/10.15407/mfint.36.11.1533
4. Breus, A., Abashin, S., Serdiuk, O., Sysoiev, Iu. (2023). Synthesis of metallic alloy particles on flat graphitic interfaces in arc discharge. *Archives of Materials Science and Engineering, 121 (2),* 49–59. https://doi.org/10.5604/01.3001.0053.8486
5. Guo, D., Kazasidis, M., Hawkins, A., Fan, N., Leclerc, Z., MacDonald, D. et al. (2022). Cold Spray: Over 30 Years of Development Toward a Hot Future. *Journal of Thermal Spray Technology, 31 (4),* 866–907. https://doi.org/10.1007/s11666-022-01366-4
6. Singh, H., Kumar, M., Singh, R. (2022). An overview of various applications of cold spray coating process. *Materials Today: Proceedings, 56,* 2826–2830. https://doi.org/10.1016/j.matpr.2021.10.160
7. Ashokkumar, M., Thirumalaikumarasamy, D., Sonar, T., Deepak, S., Vignesh, P., Anbarasu, M. (2022). An overview of cold spray coating in additive manufacturing, component repairing and other engineering applications. *Journal of the Mechanical Behavior of Materials, 31 (1),* 514–534. https://doi.org/10.1515/jmbm-2022-0056
8. Forero-Sossa, P. A., Giraldo-Betancur, A. L., Poblano-Salas, C. A., Gutierrez-Pérez, A. I., Rodríguez-Vigueras, E. M., Corona-Castuera, J., Henao, J. (2022). Nozzle Geometry and Particle Size Influence on the Behavior of Low Pressure Cold Sprayed Hydroxyapatite Particles. *Coatings, 12 (12),* 1845. https://doi.org/10.3390/coatings12121845
9. Kun, T., Wenjie, H., Yurong, W. (2024). Optimization of Cold Spray Nozzles Based on the Response Surface Methodology. *Journal of Engineering Sciences, 11 (1),* F1–F11. https://doi.org/10.21272/jes.2024.11(1).f1
10. Zahiri, S. H., Gulizia, S., Prentice, L. (2020). An Overview of Cold Spray Additive Technology in Australia for Melt-less Manufacture of Titanium. *MATEC Web of Conferences, 321,* 03011. https://doi.org/10.1051/matecconf/202032103011
11. Faizan-Ur-Rab, M., Zahiri, S. H., Masood, S. H., Jahedi, M., Nagarajah, R.; Nastac, L., Zhang, L., Thomas, B. G., Zhu, M., Ludwig, A., Sabau, A. S. (Eds.) (2016). 3D CFD Multicomponent Model for Cold Spray Additive Manufacturing of Titanium Particles. *CFD Modeling and Simulation in Materials Processing 2016. The Minerals, Metals & Materials Series.* Cham: Springer, 213–220. https://doi.org/10.1007/978-3-319-65133-0_26
12. Hu, W., Shorinov, O. (2024). Optimization of Technological Parameters for Cold Spraying Using the Response Surface Method. *Journal of Engineering Sciences, 11 (2),* F1–F8. https://doi.org/10.21272/jes.2024.11(2).f1
13. Dolmatov, A. I., Polyviany, S. A. (2021). Interaction of Solid Particles from a Gas Stream with the Surface of a Flat Nozzle. *Metallofizika i noveishie tekhnologii, 43 (3),* 319–328. https://doi.org/10.15407/mfint.43.03.0319
14. Shorinov, O., Volkov, A., Neveshkin, Y., Danko, K., Kalinichenko, N.; Ivanov, V., Pavlenko, I., Liaposhchenko, O., Machado, J., Edl, M. (Eds.) (2023). Theoretical Study of Powder Particle Parameters in a Modified Cold Spray Nozzle. *Advances in Design, Simulation and Manufacturing VI. DSMIE 2023. Lecture Notes in Mechanical Engineering.* Cham: Springer, 168–176. https://doi.org/10.1007/978-3-031-32774-2_17
15. Cao, C., Li, W., Zhang, Z., Yang, X., Xu, Y. (2022). Cold Spray Additive Manufacturing of Ti6Al4V: Special Nozzle Design Using Numerical Simulation and Experimental Validation. *Coatings, 12 (2),* 210. https://doi.org/10.3390/coatings12020210
16. Garmeh, S., Jadidi, M. (2022). Numerical Study on Particle Behavior and Deposition Accuracy in Cold Spray Additive Manufacturing. *Coatings, 12 (10),* 1546. https://doi.org/10.3390/coatings12101546
17. Shorinov, O., Volkov, A., Dolmatov, A., Balushok, K.; Tonkonogyi, V., Ivanov, V., Trojanowska, J., Oborskyi, G., Pavlenko, I. (Eds.) (2023). Numerical Simulation of a Modified Nozzle for Cold Spraying. *Advanced Manufacturing Processes V.* Cham: Springer, 571–579. https://doi.org/10.1007/978-3-031-42778-7_53
18. Tryfonov, O., Teodorczyk, A., Shypul, O., Rudy, W., Garin, V., Myntiuk, V., Tkachenko, D. (2025). Numerical Study and Model Validation of Low-Pressure Hydrogen-Air Combustion in a Closed Vessel. *Computation, 13 (2),* 54. https://doi.org/10.3390/computation13020054

ISSN-L 2664-9969; E-ISSN 2706-5448

19. *SOLIDWORKS Flow Simulation*. Available at: https://www.solidworks.com/product/solidworks-flow-simulation Last accessed: 03.06.2025
20. Schmidt, T., Gärtner, F., Assadi, H., Kreye, H. (2006). Development of a generalized parameter window for cold spray deposition. *Acta Materialia, 54 (3),* 729–742. https://doi.org/10.1016/j.actamat.2005.10.005
21. Nastic, A., Jodoin, B., Legoux, J.-G., Poirier, D. (2021). Particle Impact Characteristics Influence on Cold Spray Bonding: Investigation of Interfacial Phenomena for Soft Particles on Hard Substrates. *Journal of Thermal Spray Technology, 30 (8),* 2013–2033. https://doi.org/10.1007/s11666-021-01272-1
22. Canales, H., Lytvynov, A., Markovich, S., Dolmatov, A. (2014). Computational fluid dynamics modeling of a low pressure cold spraying nozzle. *Mechanics and Mechanical Engineering, 1,* 157–163. Available at: https://repository.kpi.kharkov.ua/handle/KhPI-Press/16980

DOI: 10.15587/2706-5448.2025.348178

DESIGN OPTIMIZATION OF A MOLD FOR PRODUCING A COMPLEX-GEOMETRY BLADE

pages 12–19

Kateryna Maiorova, *PhD, Associate Professor, Head of Department of Aircraft Manufacturing Technologies, National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine, ORCID: https://orcid.org/0000-0003-3949-0791*

Olga Shypul, *Doctor of Technical Sciences, Professor, Department of Aircraft Manufacturing Technologies, National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine, ORCID: https://orcid.org/0000-0002-1356-5831*

Ihor Lysochenko, *CNC Machine Operator, Joint-Stock Company "FED", Kharkiv, Ukraine, ORCID: https://orcid.org/0000-0002-4407-0305*

Taras Hoptar, *Stress Engineer of Fuselage Strength Calculation Design Department, Joint-Stock Company Antonov, Kyiv, Ukraine, ORCID: https://orcid.org/0009-0005-9405-6279*

Liudmyla Kapitanova, *Doctor of Technical Sciences, Associate Professor, Professor of Department of Aircraft and Helicopter Design, National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine, ORCID: https://orcid.org/0000-0003-3878-6734*

Iryna Voronko, *PhD, Associate Professor, Department of Aircraft Manufacturing Technologies, National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine, e-mail: i.voronko@khai.edu, ORCID: https://orcid.org/0000-0002-9689-6977*

The object of research is a mold with complex geometry for casting a turbine blade prototype, made by 3D printing from Anycubic photopolymer resin and PETG (Polyethylene Terephthalate Glycol) polymer.

Problem to be solved: ensuring the necessary strength and rigidity of the mold during the assembly of half-molds by bolted connection with preliminary axial tension.

Using Siemens NX Advanced Simulation, finite element models of the mold were created and calculated. It was found that with significant preliminary axial tension, the limit stresses in the bolt hole area are exceeded, which limits the use of photopolymer resin. Reducing the tightening force improves the performance, but leaves a minimum margin of safety. The rigidity of the mold can be increased by using support pads, but such a design causes stress concentration in the bolted connections. The optimal calculation result was achieved when using PETG material: the safety margin increased to $\eta = 1.5$, and the displacements did not exceed 0.04 mm. The PETG polymer, unlike photopolymer resin, is more elastic and plastic in the hardened state with higher strength. This allows to distribute the load over the material. The results obtained can be used for the manufacture of molds for casting and tooling in general, especially for a small batch of parts. The practical application of the technology under consideration is possible provided that the input parameters are correctly combined: material, bolt pre-tightening force and the use of support pads. PETG is recommended for molds operating under increased loads.

Keywords: stress-strain state, prototype, polymer molds, bolt pre-tightening simulation, additive manufacturing of tooling.

References

1. Zmarzły, P., Gogolewski, D., Kozior, T. (2020). Design guidelines for plastic casting using 3D printing. *Journal of Engineered Fibers and Fabrics,* 15. https://doi.org/10.1177/1558925020916037
2. Parthiban, P., Vijayan, S., Doyle, P. S., Hashimoto, M. (2021). Evaluation of 3D-printed molds for fabrication of non-planar microchannels. *Biomicrofluidics, 15 (2).* https://doi.org/10.1063/5.0047497
3. Gao, W., Zhang, Y., Ramanujan, D., Ramani, K., Chen, Y., Williams, C. B. et al. (2015). The status, challenges, and future of additive manufacturing in engineering. *Computer-Aided Design, 69,* 65–89. https://doi.org/10.1016/j.cad.2015.04.001
4. Vigogne, M., Zschech, C., Stommel, M., Thiele, J., Kühnert, I. (2024). Combining Injection Molding and 3D Printing for Tailoring Polymer Material Properties. *Macromolecular Materials and Engineering, 309 (11).* https://doi.org/10.1002/mame.202400210
5. Grzejda, R., Warzecha, M., Urbanowicz, K. (2022). Determination of the Preload of Bolts for Structural Health Monitoring of a Multi-Bolted Joint: FEM Approach. *Lubricants, 10 (5),* 75. https://doi.org/10.3390/lubricants10050075
6. Chai, R., Yu, Z., Xu, H., Huang, X., Mao, K., Zhou, W. (2025). Pre-tightening Force Analysis of Different Bolt Models Based on Finite Element Simulation. *Advances in Engineering Technology Research, 14 (1),* 496. https://doi.org/10.56028/aetr.14.1.496.2025
7. Belardi, V. G., Fanelli, P., Vivio, F.; Chen, S. M. (Ed.) (2022). Comparative Analysis of FE Modeling Techniques for Single-Lap Multi-column Composite Bolted Joints. *Proceedings of 10th International Conference on Chemical Science and Engineering.* Singapore: Springer, 121–128. https://doi.org/10.1007/978-981-19-4290-7_14
8. Lupkin, B., Maiorova, K., Vorobiov, I., Nikichanov, V., Sikulskyi, V.; Nechyporuk, M., Pavlikov, V., Kritskiy, D. (Eds.) (2023). Study of Drilling Cutting Modes Impact on Shrinkage and Surface Roughness of Holes in Composite Materials. *Integrated Computer Technologies in Mechanical Engineering – 2022.* Cham: Springer, 88–98. https://doi.org/10.1007/978-3-031-36201-9_8
9. Myntiuk, V., Shypul, O., Tryfonov, O., Tsegelnyk, Y. (2025). Axisymmetric problem of smoothing the surface of a viscous liquid by surface tension forces. *Radioelectronic and Computer Systems, 2025 (1),* 113–125. https://doi.org/10.32620/reks.2025.1.08
10. Maiorova, K., Lysochenko, I., Skyba, O., Suslov, A., Antonyuk, V.; Pavlenko, D., Tryshyn, P., Honchar, N., Kozlova, O. (Eds.) (2025). Analysis of Modern Approaches to Approbation of Aircraft Parts Geometric Data Digitization by Reverse Engineering. *Smart Innovations in Energy and Mechanical Systems.* Cham: Springer, 264–273. https://doi.org/10.1007/978-3-031-95191-6_25
11. Onopchenko, A., Horbachov, O., Sorokin, V., Dudukalov, Y., Kurin, M.; Tonkonogyi, V., Ivanov, V., Trojanowska, J., Oborskyi, G., Pavlenko, I. (Eds.) (2022). Optimal Conditions for Deformation of Stamping-Drawing Process from Aviation Materials. *Advanced Manufacturing Processes IV.* Cham: Springer, 109–118. https://doi.org/10.1007/978-3-031-16651-8_11
12. Shevel, V., Kritskiy, D., Popov, O. (2022). Toward Building a Functional Image of the Design Object in CAD. *Computation, 10 (8),* 134. https://doi.org/10.3390/computation10080134
13. Onopchenko, A. V., Kurin, M. O., Shyrokyi, Y. V. (2024). Ensuring quality of stamping sheet aviation parts. *Progress in Physics of Metals, 25 (2),* 320–363. https://doi.org/10.15407/ufm.25.02.320

DOI: 10.15587/2706-5448.2025.348608

DETERMINATION OF THE EFFICIENCY OF SHOT BLASTING OF METAL SURFACES

pages 20–25

Oleksii Goryk, *Doctor of Technical Sciences, Professor, Department of Construction and Vocational Education, Poltava State Agrarian University, Poltava, Ukraine, e-mail: oleksii.goruk@pdau.edu.ua, ORCID: https://orcid.org/0000-0002-2804-5580*

Oleksandr Brykun, *PhD, Associate Professor, Department of Construction and Vocational Education, Poltava State Agrarian University, Poltava, Ukraine, ORCID: https://orcid.org/0000-0001-5213-9440*

Oleg Kalashnykov, *Department of Oil and Gas Engineering and Technology, LLC Poltava Drilling Company, Poltava, Ukraine, ORCID: https://orcid.org/0009-0005-7836-3930*

Andrii Buchynskyi, *Department of Oil and Gas Engineering and Technology, National University Yuri Kondratyuk Poltava Polytechnic, Poltava, Ukraine, ORCID: https://orcid.org/0000-0001-7154-6404*

The object of this research is the process of transformation of kinetic energy of the attacking air-abrasive torch in the process of dynamic impact on metal surfaces of products during their shot blasting.

The importance of the research is due to the need to solve the problem of increasing the efficiency of the technological process of preparing metal surfaces of products by shot blasting for the subsequent application of protective, stable non-metallic coatings.

In the work, based on the energy balance of the "shot-obstacle" system, a method for determining the efficiency coefficient of the shot blasting surface preparation process was developed, which was associated with the torch energy recovery coefficient. The relationship of the coefficients with the potential energy of the surface layer accumulated in the process of elastic deformation was established. The depth of the hole formed by the shot on the surface of the attacked body was taken as a measure of this energy. When determining the depth of the hole, the deformati on of an elementary cylindrical element clamped in the surface layer of the attacked body was considered, the dimensions of which are compatible with the dimensions of the elastic deformation hole.

The classical recovery coefficient is not a characteristic criterion for revealing the physical aspects of the complex multifactorial shot blasting process. The ease of application in practical calculations, especially when establishing the productivity of the process, prompts the search for improving the methods of its determination, since the existing models of an ideal impact in this case are not capable. This coefficient at average attack speeds of 100–120 m/s and angles of $40° < \alpha < 70°$ turned out to be 15–20% less than the classical one.

The obtained research results can be used to increase the productivity of the shot blasting process of products of the defense, agricultural, machine-building, chemical, aviation and other industries.

Keywords: energy balance, shot blasting, efficiency, ricochet velocity.

References

1. Boettcher, R., Kunik, M., Eichmann, S., Russell, A., Mueller, P. (2017). Revisiting energy dissipation due to elastic waves at impact of spheres on large thick plates. *International Journal of Impact Engineering, 104,* 45–54. https://doi.org/10.1016/j.ijimpeng.2017.02.012
2. Goryk, O., Koval'chuk, S., Brykun, O., Aksonov, S. (2022). Assessment of Quality Criteria of Shot Blasting Cleaning of the Inner Surfaces of Chemically Resistant Containers. *Advances in Mechanical and Power Engineering,* 98–107. https://doi.org/10.1007/978-3-031-18487-1_10
3. Basdeki, M., Apostolopoulos, C. (2022). The Effect of the Shot Blasting Process on the Dynamic Response of Steel Reinforcement. *Metals, 12 (6),* 1048. https://doi.org/10.3390/met12061048
4. Lai, J., Shen, X., Yuan, X., Li, D., Gong, X., Zhao, F. et al. (2024). The Effect of Shot Blasting Abrasive Particles on the Microstructure of Thermal Barrier Coatings Containing Ni-Based Superalloy. *Coatings, 14 (10),* 1312. https://doi.org/10.3390/coatings14101312
5. Melentiev, R. (2023). Physical theories of solid particle erosion and abrasive jet wear. *Journal of Manufacturing Processes, 106,* 422–452. https://doi.org/10.1016/j.jmapro.2023.10.014
6. Yang, J., Qu, K., Yang, J. (2021). Fatigue performance of Q355B steel substrate treated by grit blasting with and without subsequent cold spraying with Al and Cu. *Surface and Coatings Technology, 405,* 126662. https://doi.org/10.1016/j.surfcoat.2020.126662
7. Tawade, P., Shembale, S., Hussain, S., Sabiruddin, K. (2023). Effects of Different Grit Blasting Environments on the Prepared Steel Surface. *Journal of Thermal Spray Technology, 32 (5),* 1535–1553. https://doi.org/10.1007/s11666-023-01585-3
8. Melo, K. R. B., de Pádua, T. F., Lopes, G. C. (2021). A coefficient of restitution model for particle–surface collision of particles with a wide range of mechanical characteristics. *Advanced Powder Technology, 32 (12),* 4723–4733. https://doi.org/10.1016/j.apt.2021.10.023
9. Liu, X., Chen, W., Shi, H. (2022). Improvement of Contact Force Calculation Model Considering Influence of Yield Strength on Coefficient of Restitution. *Energies, 15 (3),* 1041. https://doi.org/10.3390/en15031041
10. Li, T., Li, R., Chi, Z., Zhang, Y., Yang, H. (2024). Experimental Study on Coefficient of Restitution of Small-Sized Spherical Particles during Low-Speed Impact. *Condensed Matter, 9 (1),* 18. https://doi.org/10.3390/condmat9010018
11. Chen, X., Wang, L.-W., Yu, Q., Zhang, F., Mo, K., Ming, S.-L. et al. (2022). Experimental and Numerical Analysis on the Impact Wear Behavior of TP316H Steel. *Materials, 15 (8),* 2881. https://doi.org/10.3390/ma15082881
12. Meyer, N., Wagemann, E. L., Jackstadt, A., Seifried, R. (2022). Material and particle size sensitivity analysis on coefficient of restitution in low-velocity normal impacts. *Computational Particle Mechanics, 9 (6),* 1293–1308. https://doi.org/10.1007/s40571-022-00471-z
13. Tarodiya, R., Levy, A. (2024). Numerical investigation of collision characteristics of non-spherical particles on ductile surfaces under normal impact. *Computational Particle Mechanics, 11 (6),* 2693–2699. https://doi.org/10.1007/s40571-024-00746-7
14. Green, I. (2022). The prediction of the coefficient of restitution between impacting spheres and finite thickness plates undergoing elastoplastic deformations and wave propagation. *Nonlinear Dynamics, 109 (4),* 2443–2458. https://doi.org/10.1007/s11071-022-07522-3
15. Gorik, A. V., Zinkovskii, A. P., Chernyak, R. E., Brikun, A. N. (2016). Elastoplastic Deformation of the Surface Layer of Machinery Constructions on Shot Blasting. *Strength of Materials, 48 (5),* 650–657. https://doi.org/10.1007/s11223-016-9808-6
16. Goryk, O., Koval'chuk, S., Brykun, O., Lapenko, T. (2023). The stability period of attacking shots in the process of shot blasting of metal surfaces. *IX international conference on actual problems of engineering mechanics (APEM2022),* 2840, 030002. https://doi.org/10.1063/5.0167634
17. Goryk, O., Koval'chuk, S., Brykun, O., Chernyak, R. (2020). Viscoelastic Resistance of the Surface Layer of Steel Products to Shock Attack of a Spherical Pellet. *Key Engineering Materials, 864,* 217–227. https://doi.org/10.4028/www.scientific.net/kem.864.217
18. Fan, Y., Wang, H., Zhou, T., Zou, L., Jiang, Z., Hu, M. (2024). Prediction of Coefficient of Restitution for Impact Elastoplastic Spheres Considering Finite Plate Thickness. *Chinese Journal of Mechanical Engineering, 37 (1).* https://doi.org/10.1186/s10033-024-01066-w
19. Ji, Z.-M., Chen, Z.-J., Niu, Q.-H., Wang, T.-H., Wang, T.-J. et al. (2020). A calculation model of the normal coefficient of restitution based on multi-factor interaction experiments. *Landslides, 18 (4),* 1531–1553. https://doi.org/10.1007/s10346-020-01556-7
20. Xie, X., Zhang, L., Zhu, L., Li, Y., Hong, T., Yang, W. et al. (2023). State of the Art and Perspectives on Surface-Strengthening Process and Associated Mechanisms by Shot Peening. *Coatings, 13 (5),* 859. https://doi.org/10.3390/coatings13050859

MECHANICS

DOI: 10.15587/2706-5448.2025.346717

ANALYTICAL DETERMINATION OF ABSOLUTE DEFORMATIONS AND BOUNDARIES OF THE CONTACT ZONE OF A DEFORMABLE WHEEL WITH A DEFORMABLE SURFACE

pages 26–33

Volodymyr Kovbasa, *Doctor of Technical Sciences, Professor, Department of Mechanical and Electrical Engineering, Poltava State Agrarian University, Poltava, Ukraine, ORCID: https://orcid.org/0000-0003-4574-5826*

Nataliia Priliepo, *Department of Mechanical and Electrical Engineering, Poltava State Agrarian University, Poltava, Ukraine, e-mail: nataliia.pryliepo@pdau.edu.ua, ORCID: https://orcid.org/0000-0002-4182-7405*

The object of research is the contact interaction between a deformable wheel (tire) and a deformable supporting surface. One of the most problematic areas is defining the boundaries of the contact zone as a function of applied loads, wheel geometry, and the mechanical properties of the contacting surfaces, as well as the increasing need to reduce

ISSN-L 2664-9969; E-ISSN 2706-5448

energy consumption and soil compaction in the context of vehicle running gear systems.

During the research, methods from the mechanics of continuous deformable media were used to identify the deformable properties of contacting surfaces. The investigations were founded on previously published research concerning the distribution of contact forces, obtained using biharmonic potential analytical functions based on methods employed by Boussinesq and Cerruti.

Analytical dependencies have been derived that relate the leading and trailing edges of the deformable wheel's (tire's) contact with the deformable surface. This is because the proposed approach, which considers the relationship between forces and displacements on the surface and deformations and stresses within the contacting bodies, taking into account their mechanical properties, is more informative compared to methods of theoretical and analytical mechanics. The research revealed that the potential for improving the object's functioning lies in optimizing the selection of parameters and operating modes for running gear systems.

Thanks to this, it becomes possible to obtain optimized values for the geometric size of the contact surface. Compared to analogous known approaches, this ensures an enhancement in the tractive efficiency of driving wheels, minimizing wheel slip to acceptable levels, which directly addresses key challenges in agricultural and off-road machinery by contributing to reduced energy consumption and soil compaction.

Keywords: deformable wheel, deformable support surface, absolute deformations, contact zone boundaries.

References

1. Johnson, K. L. (1985). *Contact Mechanics*. London: Cambridge University Press. https://doi.org/10.1017/cbo9781139171731
2. Kovbasa, V. P. (2006). *Mekhaniko-tekhnolohichne obgruntuvannia optymizatsii robochykh orhaniv z gruntom*. [Doctoral dissertation; Natsionalnyi universytet bioresursiv i pryrodokorystuvannia Ukrainy]. Available at: https://uacademic.info/ua/document/0506U000111#!
3. Guthrie, A. G., Botha, T. R., Els, P. S. (2017). 3D contact patch measurement inside rolling tyres. *Journal of Terramechanics, 69,* 13–21. https://doi.org/10.1016/j.jterra.2016.09.004
4. Yamashita, H., Jayakumar, P., Alsaleh, M., Sugiyama, H. (2017). Physics-Based Deformable Tire–Soil Interaction Model for Off-Road Mobility Simulation and Experimental Validation. *Journal of Computational and Nonlinear Dynamics, 13 (2).* https://doi.org/10.1115/1.4037994
5. Kushnarov, A. S., Kochev, V. I. (1989). *Mekhaniko-tekhnologicheskie osnovy obrabotki pochvy*. Kyiv: Urozhai, 144.
6. Johnson, W., Mellor, P. B. (1973). *Engineering plasticity*. London, New York: Van Nostrand Reinhold Co. Available at: https://www.scribd.com/document/489339320/Engineering-Plasticity-by-W-Johnson-and-P-B-Mellor-pdf
7. Kovbasa, V. P., Solomka, A. V., Spirin, A. V., Kucheruk, V. Yu., Karabekova, D. Zh., Khassenov, A. K. (2020). Theoretical determination of the distribution of forces and the size of the boundaries of the contact in the interaction of the deformable drive wheel with the soil. *Bulletin of the Karaganda University "Physics Series", 99 (3),* 62–72. https://doi.org/10.31489/2020ph3/62-72
8. Kovbasa, V., Priliepo, N. (2025). Determination of analytical dependencies of distributed forces in a deformable wheel – deformable surface contact zone. *Technology Audit and Production Reserves, 3 (1 (83)),* 6–12. https://doi.org/10.15587/2706-5448.2025.329471
9. Yang, W., Tiecheng, S., Yongjie, L., Chundi, S. (2016). Prediction for Tire – Pavement Contact Stress under Steady – State Conditions based on 3D Finite Element Method. *Journal of Engineering Science and Technology Review, 9 (4),* 17–25. https://doi.org/10.25103/jestr.094.04
10. Swamy, V. S., Pandit, R., Yerro, A., Sandu, C., Rizzo, D. M., Sebeck, K., Gorsich, D. (2023). Review of modeling and validation techniques for tire-deformable soil interactions. *Journal of Terramechanics, 109,* 73–92. https://doi.org/10.1016/j.jterra.2023.05.007

DOI: 10.15587/2706-5448.2025.339423

EVALUATION OF PRAGER AND CHABOCHE MODELS FOR RELIABLE PREDICTION OF ELASTOPLASTIC BEHAVIOUR IN LOW-CYCLE FATIGUE

pages 34–42

Amira Aboussalih, *Researcher, Department of Mechanic, Institute of Applied Sciences and Techniques (ISTA), University Frères Mentouri Constantine 1, Constantine, Algeria, ORCID: https://orcid.org/0009-0000-5783-5429*

Salah Hammoudi, *Researcher, Department of Mechanic, Institute of Applied Sciences and Techniques (ISTA), University Frères Mentouri Constantine 1, Constantine, Algeria, ORCID: https://orcid.org/0009-0008-0382-1206*

Kamel Fedaoui, *PhD, The Laboratory of Renewable Energy, Energy Efficiency and Smart Systems (LEREESI), Higher National School of Renewable Energy, Environment & Sustainable Development (RE2SD), Batna, Algeria, e-mail: K.fedaoui@hns-re2sd.dz, ORCID: https://orcid.org/0000-0003-0885-6914*

Lazhar Baroura, *Researcher, Department of Mechanic, Institute of Applied Sciences and Techniques (ISTA), University Frères Mentouri Constantine 1, Constantine, Algeria, ORCID: https://orcid.org/0000-0002-6747-5049*

Karim Arar, *Researcher, Department of Mechanic, Batna 2 University, Batna, Algeria, ORCID: https://orcid.org/0009-0004-5951-0846*

The object of this research is the cyclic elastoplastic behavior of materials, principally austenitic stainless steel (304L). The paper studies the 304L stainless steel behavior of exposed to different uniaxial and multiaxial cyclic loadings. It also determines the accuracy with which classical models, such as the Prager model, reproduce the phenomena of work hardening. All the models have which limits the reliability of fatigue life predictions for structures. For that, in this numerical study, a comparative analysis is performed between the Prager model and the Chaboche model. Chaboche model was selected to overcome the shortcomings of classical approaches, it can incorporate isotropic and nonlinear kinematic work hardening together. Numerous numerical simulations were conducted under various loading scenarios allowed to estimate the predictive capacity of the constitutive models and the limitations of simplified linear approaches. The results obtained, show that Chaboche model reproduces with excellent accuracy the phenomena of work hardening, additional work hardening, and ratcheting compared to the Prager model. This is explained by the fact that the Chaboche model can take into account the coupling between different phenomena which guarantees a realistic representation of cyclic elastoplastic behavior. Compared to similar models known in the literature, the Chaboche approach offers significant advantages: increased predictive accuracy, better representation of complex cyclic phenomena, and a fatigue life assessment of 304L stainless steel that closely reflects reality in demanding industrial applications.

Keywords: Prager model, Chaboche model, 304L SS, cyclic, ratcheting, hardening, fatigue.

References

1. Chaboche, J.-L. (1981). Continuous damage mechanics – A tool to describe phenomena before crack initiation. *Nuclear Engineering and Design, 64 (2),* 233–247. https://doi.org/10.1016/0029-5493(81)90007-8
2. Chaboche, J. L. (2008). A review of some plasticity and viscoplasticity constitutive theories. *International Journal of Plasticity, 24 (10),* 1642–1693. https://doi.org/10.1016/j.ijplas.2008.03.009
3. Subasic, M., Alfredsson, B., Dahlberg, C. F. O., Öberg, M., Efsing, P. (2023). Mechanical Characterization of Fatigue and Cyclic Plasticity of 304L Stainless Steel at Elevated Temperature. *Experimental Mechanics, 63 (8),* 1391–1407. https://doi.org/10.1007/s11340-023-00992-5
4. Azizoğlu, Y., Lindgren, L.-E. (2024). Temperature and plastic strain dependent Chaboche model for 316 L used in simulation of cold pilgering. *International Journal of Material Forming, 18 (1).* https://doi.org/10.1007/s12289-024-01864-6
5. Skrzat, A., Wójcik, M. (2023). Explicit and Implicit Integration of Constitutive Equations of Chaboche Isotropic-Kinematic Hardening Material Model. *Acta Metallurgica Slovaca, 29 (4),* 200–205. https://doi.org/10.36547/ams.29.4.1949
6. Belattar, A., Taleb, L. (2021). Experimental and numerical analyses of the cyclic behavior of austenitic stainless steels after prior inelastic histories. *International Journal of Pressure Vessels and Piping, 189,* 104256. https://doi.org/10.1016/j.ijpvp.2020.104256
7. Kebir, T., Benguediab, M., Miloudi, A., Imad, A. (2017). Simulation of The Cyclic Hardening Behavior of luminum Alloys. *Scientific Bulletin-University Politehnica*

of Bucharest. Series D, 79 (4), 240–250. Available at: https://www.scientificbulletin.upb.ro/rev_docs_arhiva/rezb11_236576.pdf

8. Boussalih, F., Meziani, S., Fouathia, A., Fedaoui, K. (2019). Behavior of 304L stainless steel under uniaxial loading and effect of the mean stress on the ratcheting by simulation using Chaboche model. *Scientific Bulletin-University Politehnica of Bucharest. Series D, 81 (2),* 179–190. https://www.scientificbulletin.upb.ro/rev_docs_arhiva/fullaee_340862.pdf
9. Acar, S. S., Yalçinkaya, T. (2025). Modeling of the Stress Path-Dependent Strain Ratcheting Behaviour of 304L Stainless Steel Through Crystal Plasticity Frameworks. *Metals and Materials International, 31 (9),* 2525–2540. https://doi.org/10.1007/s12540-025-01907-w
10. Taleb, L., Hauet, A. (2009). Multiscale experimental investigations about the cyclic behavior of the 304L SS. *International Journal of Plasticity, 25 (7),* 1359–1385. https://doi.org/10.1016/j.ijplas.2008.09.004
11. Delobelle, P., Robinet, P., Bocher, L. (1995). Experimental study and phenomenological modelization of ratchet under uniaxial and biaxial loading on an austenitic stainless steel. *International Journal of Plasticity, 11 (4),* 295–330. https://doi.org/10.1016/s0749-6419(95)00001-1
12. Boussalih, F., Fedaoui, K., Zarza, T. (2022). Chaboche Model for Fatigue by Ratcheting Phenomena of Austenitic Stainless Steel under Biaxial Sinusoidal Loading. *Civil Engineering Journal, 8 (3),* 505–518. https://doi.org/10.28991/cej-2022-08-03-07
13. Mazánová, V., Polák, J., Škorík, V., Kruml, T. (2017). Multiaxial elastoplastic cyclic loading of austenitic 316L steel. *Frattura Ed Integrità Strutturale, 11 (40),* 162–169. https://doi.org/10.3221/igf-esis.40.14
14. Chaboche, J. L. (1989). Constitutive equations for cyclic plasticity and cyclic viscoplasticity. *International Journal of Plasticity, 5 (3),* 247–302. https://doi.org/10.1016/0749-6419(89)90015-6
15. Djimli, L., Taleb, L., Meziani, S. (2010). The role of the experimental data base used to identify material parameters in predicting the cyclic plastic response of an austenitic steel. *International Journal of Pressure Vessels and Piping, 87 (4),* 177–186. https://doi.org/10.1016/j.ijpvp.2010.02.002

METALLURGICAL TECHNOLOGY

DOI: 10.15587/2706-5448.2025.345473

DETERMINATION OF CONDITIONS FOR PREVENTING CHEMICAL WEAR OF INDUCTION FURNACE LINING IN THE "CUPOLA FURNACE – INDUCTION FURNACE" DUPLEX PROCESS

pages 43–47

Denis Nikolaev, *PhD Student, Department of Foundry, National Technical University "Kharkiv Polytechnic Institute", Kharkiv, Ukraine, ORCID: https://orcid.org/0000-0002-8324-1760, e-mail: nikolaev@entc.com.ua*

Vadym Selivorstov, *Doctor of Technical Sciences, Professor, Department of Foundry Production, Ukrainian State University of Science and Technologies, Dnipro, Ukraine, ORCID: https://orcid.org/0000-0002-1916-625X*

Yuriy Dotsenko, *PhD, Associate Professor, Department of Foundry Production, Ukrainian State University of Science and Technologies, Dnipro, Ukraine, ORCID: https://orcid.org/0000-0002-7734-7884*

Iryna Osypenko, *PhD, Associate Professor, Department of Foundry Production, Ukrainian State University of Science and Technologies, Dnipro, Ukraine, ORCID: https://orcid.org/0000-0002-7119-9278*

Eugene Kuznetsow, *PhD, Associate Professor, Department of Physics and Applied Mathematics, Educational and Research Institute "Dnipro Institute of Infrastructure and Transport" of the Ukrainian State University of Science and Technology, Dnipro, Ukraine, ORCID: https://orcid.org/0000-0002-4326-8539*

The object of research is the melting of cast iron in the "cupola furnace – induction furnace" duplex process. The need to study such a duplex process is dictated by the condition of ensuring the required quality of cast iron in the event that a low-quality or uncontrolled charge is used. This condition cannot be met if the induction furnace is used as the only melting unit. But the problem is that in the process of induction melting of cast iron, in particular at the stage of overheating and holding the melt, a crucible reaction may begin, which leads to chemical wear of the lining. The need to reduce the carbon content in the melt discharged from the cupola furnace requires an increase in temperatures, which creates risks for the onset of a crucible reaction.

Based on statistical calculations of cupola melting parameters, it was found that in the melt discharged from the cupola furnace into the induction furnace, the average carbon content is C = 3.47% with a standard deviation S_C = 0.14%, and the average silicon content is Si = 2.05% with a standard deviation S_{Si} = 0.21%. At the same time, with a probability of 96%, the carbon content is C = (3.33–3.75)%, and the silicon content corresponds to the range Si = (1.84–2.46)% with a probability of 98%. It was found that the equilibrium constant is in the range (0.15–0.21) with a probability of 97.8% at an average temperature T = 1355°C with a standard deviation of temperature S_T = 6°C. With such melt parameters, which are supplied to the induction furnace, the risks of the onset of a crucible reaction do not arise. It was determined that even at temperature regimes sufficient to remove FeO, the risk of the onset of a crucible reaction is minimal. In order to ensure conditions that prevent the onset of a crucible reaction, the following recommendations should be followed for the content of carbon and silicon in high-temperature melting when the temperature is in the range T > 1480°C: C > 0.3% and Si < 0.3%.

The results of the study can be used in the melting sections of foundries equipped with cupola furnaces and induction furnaces.

Keywords: "cupola furnace – induction furnace" duplex processes, crucible reaction, chemical wear of the lining, poor-quality charge.

References

1. Demin, D., Frolova, L. (2024). Construction of a logical-probabilistic model of casting quality formation for managing technological operations in foundry production. *EUREKA: Physics and Engineering, 6,* 104–118. https://doi.org/10.21303/2461-4262.2024.003518
2. Demin, D. (2023). Experimental and industrial method of synthesis of optimal control of the temperature region of cupola melting. *EUREKA: Physics and Engineering, 2,* 68–82. https://doi.org/10.21303/2461-4262.2023.002804
3. Ajah, S. A., Idorenyin, D., Nwokenkwo, U. C., Nwigwe, U. S., Ezurike, B. O. (2021). Thermal Analysis of a Conventional Cupola Furnace with Effects of Excess Air on the Flue Gases Specific Heat. *Journal of Materials and Environmental Science, 12 (2),* 192–204.
4. Jopkiewicz, A., Podrzucki, C. (2007). Tendencies to the Improvement of the Cupola Process. *Archives of foundry engineering, 13 (3),* 61–70.
5. Nikolaiev, D., Selivorstov, V., Dotsenko, Y., Dzevochko, O., Pereverzieva, A., Dzevochko, A. (2025). Identification of temperature in cupola furnace based on the construction of the "slag composition – slag viscosity" model. *Technology Audit and Production Reserves, 1 (1 (81)),* 29–33. https://doi.org/10.15587/2706-5448.2025.322458
6. Nikolaiev, D. (2024). Construction of a cupola information profile for further modeling for the purpose of controlling melting processes. *ScienceRise, 2,* 3–14. https://doi.org/10.21303/2313-8416.2024.003674
7. Demin, D. (2025). Optimization of parameters of the cupola melting by the criterion of the maximum cast iron temperature. *EUREKA: Physics and Engineering, 2,* 158–165. https://doi.org/10.21303/2461-4262.2025.003712
8. Demin, D. A. (2012). Synthesis of optimal temperature regulator of electroarc holding furnace bath. *Scientific Bulletin of National Mining University, 6,* 52–58.
9. Demin, D. (2014). Mathematical description typification in the problems of synthesis of optimal controller of foundry technological parameters. *Eastern-European Journal of Enterprise Technologies, 1 (4 (67)),* 43–56. https://doi.org/10.15587/1729-4061.2014.21203
10. Demin, D. (2013). Adaptive modeling in problems of optimal control search termovremennoy cast iron. *Eastern-European Journal of Enterprise Technologies, 6 (4 (66)),* 31–37. https://doi.org/10.15587/1729-4061.2013.19453
11. Demin, D. (2014). Computer-integrated electric-arc melting process control system. *Eastern-European Journal of Enterprise Technologies, 2 (9 (68)),* 18–23. https://doi.org/10.15587/1729-4061.2014.23512

ISSN-L 2664-9969; E-ISSN 2706-5448

12. Demin, D. (2017). Synthesis of optimal control of technological processes based on a multialternative parametric description of the final state. *Eastern-European Journal of Enterprise Technologies, 3 (4 (87))*, 51–63. https://doi.org/10.15587/1729-4061.2017.105294

13. Demin, D. (2020). Constructing the parametric failure function of the temperature control system of induction crucible furnaces. *EUREKA: Physics and Engineering, 6,* 19–32. https://doi.org/10.21303/2461-4262.2020.001489

14. Stanovska, I., Duhanets, V., Prokopovych, L., Yakhin, S. (2021). Classification rule for determining the temperature regime of induction gray cast iron. *EUREKA: Physics and Engineering, 1,* 60–66. https://doi.org/10.21303/2461-4262.2021.001604

15. Penziev, P., Lavryk, Y. (2023). Diagnostics of the temperature condition of cast iron melting in induction furnaces by the content of SiO_2 and CaO in slag. *ScienceRise, 1,* 14–20. https://doi.org/10.21303/2313-8416.2024.003558

16. Demin, D., Domin, O. (2021). Adaptive technology for constructing the kinetic equations of reduction reactions under conditions of a priori uncertainty. *EUREKA: Physics and Engineering, 4,* 14–29. https://doi.org/10.21303/2461-4262.2021.001959

17. Lysenkov, V. Yu. (2025). Systematyzovani dani po khimichnomu skladu chavunu vahranochnoi plavky dlia vyhotovlennia tonkostinnykh vylyvkiv. *Teoretychni ta praktychni doslidzhennia molodykh vchenykh.* Kharkiv: NTU "KhPI", 735–736.

18. Lavryk, Ye. Ye. (2025). Vyznachennia vplyvu rezhymiv induktsiinoi plavky na kilkist nemetalevykh vkliuchen v ridkomu chavuni. *Teoretychni ta praktychni doslidzhennia molodykh vchenykh.* Kharkiv: NTU "KhPI", 732–733.

TECHNOLOGY AND SYSTEM OF POWER SUPPLY

DOI: 10.15587/2706-5448.2025.344908

DEVELOPMENT OF A METHOD FOR MODELING THE MAGNETIC STATE AND ASSESSING THE ELECTROMECHANICAL CHARACTERISTICS OF A VORTEX LAYER OF FERROMAGNETIC PARTICLES MOVING IN A ROTATING MAGNETIC FIELD

pages 48–56

Henrikh Polshchikov, *Head of the Electromagnetic Devices Sector (retired), Department of Vortex Mixing Apparatus, Private Joint Stock Company "Research and Development Institute of Enameled Chemical Equipment and New Technologies Kolan", Poltava, Ukraine, e-mail: genrikharonovich@gmail.com, ORCID: https://orcid.org/0009-0001-2197-2373*

Pavlo Zhukov, *Electrician Engineer (retired), Private Joint Stock Company "Research and Development Institute of Enameled Chemical Equipment and New Technologies Kolan", Poltava, Ukraine, ORCID: https://orcid.org/0009-0005-5661-0275*

The object of this study is a vortex layer (VL) of ferromagnetic particles (FP) moving in a rotating magnetic field (RMF). Apparatuses vortex layer (AVL) devices are used to intensify energy-intensive technological processes with liquid and bulk materials that require activation, mixing, and fine grinding. External three-phase (380 V/50 Hz) two-pole inductors are used to synthesize the VL in a cylindrical AVL working chamber with a diameter of 60–330 mm. The RMF_i modulus of magnetic induction at the bore center in the absence of FP is selected during design from the range of 0.12–0.25 T. Steel or nickel FPs have an elongated cylindrical shape, typically with a ratio of $l/d = 8–15$ (l is the FP length, d is the FP diameter) and a diameter of 0.7–2.5 mm. The magnetic and electromechanical characteristics of the VL have been insufficiently studied. This paper examines a method for estimating these characteristics of the VL by modeling its magnetic state. A real bipolar RMF existing in a working chamber with an operating VL is represented by the synchronous rotation of three plane-parallel uniform circular vector fields – field strength, induction, and magnetization $\vec{H}, \vec{B}, \vec{J}$. The experimental determination of the characteristics of the model vectors $\vec{H}, \vec{B}, \vec{J}$ is performed using two flat frame induction coils. The simple behavior patterns of the vector field are consistent with the relatively chaotic behavior of each individual VL particle.

A demonstration example of determining the characteristics of the model vectors $\vec{H}, \vec{B}, \vec{J}$, the specific torque magnetic moment, the specific power, and the level of chaos of an industrial VL is presented.

The results of this work can be used in both academic and engineering applications related to the research and design of AVL and similar equipment.

Keywords: vortex layer in RMF, electromechanical interaction FP, magnetization model VL, optimal FP concentration, VL chaos level.

References

1. Moerland, C. P., van IJzendoorn, L. J., Prins, M. W. J. (2019). Rotating magnetic particles for lab-on-chip applications – a comprehensive review. *Lab on a Chip, 19 (6),* 919–933. https://doi.org/10.1039/c8lc01323c

2. Logvinenko, D. D., Sheliakov, O. P. (1976). *Intensifikatciia tekhnologicheskikh protcessov v apparatakh s vikhrevym sloem.* Kyiv: Tekhnika, 144.

3. Oberemok, V. M. (2010). *Elektromahnitni aparaty z feromahnitnymy robochymy elementamy. Osoblyvosti zastosuvannia.* Poltava: RVV PUSKU, 201. Available at: http://dspace.puet.edu.ua/handle/123456789/6536

4. *GlobeCore Transformer Oil Purification Equipment, Bitumen Equipment.* Available at: https://globecore.com/ Last accessed: 22.09.2023

5. Ogonowski, S. (2021). On-Line Optimization of Energy Consumption in Electromagnetic Mill Installation. *Energies, 14 (9),* 2380. https://doi.org/10.3390/en14092380

6. Ibragimov, R., Korolev, E., Potapova, L., Deberdeev, T., Khasanov, A. (2022). The Influence of Physical Activation of Portland Cement in the Electromagnetic Vortex Layer on the Structure Formation of Cement Stone: The Effect of Extended Storage Period and Carbon Nanotubes Modification. *Buildings, 12 (6),* 711. https://doi.org/10.3390/buildings12060711

7. Calus, D. (2023). Experimental Research into the Efficiency of an Electromagnetic Mill. *Applied Sciences, 13 (15),* 8717. https://doi.org/10.3390/app13158717

8. Polshchikov, H., Zhukov, P. (2023). Force effect of a circular rotating magnetic field of a cylindrical electric inductor on a ferromagnetic particle in process reactors. *Technology Audit and Production Reserves, 6 (1 (74)),* 34–40. https://doi.org/10.15587/2706-5448.2023.293005

9. Polshchikov, H., Zhukov, P. (2024). Construction of a generalized mathematical model and fast calculations of plane-parallel rotating magnetic fields in process reactors with longitudinal currents of cylindrical inductors on a graphical calculator. *Technology Audit and Production Reserves, 5 (1 (79)),* 38–49. https://doi.org/10.15587/2706-5448.2024.313937

10. Hallali, N., Rocacher, T., Crouzet, C., Béard, J., Douard, T., Khalfaoui, A. et al. (2022). Low-frequency rotating and alternating magnetic field generators for biological applications: Design details of home-made setups. *Journal of Magnetism and Magnetic Materials, 564,* 170093. https://doi.org/10.1016/j.jmmm.2022.170093

11. Polshchikov, G. A., Logvinenko, D. D., Zhukov, P. B. (1975). Nekotorye voprosy rascheta i proektirovaniia apparatov s vikhrevym sloem, NIIKhIMMASh. *Oborudovanie s ispolzovaniem razlichnykh metodov intensifikatcii protcessov, 71,* 128–141.

12. Milykh, V. I., Shilkova, L. V. (2020). Characteristics of a cylindrical inductor of a rotating magnetic field for technological purposes when it is powered from the mains at a given voltage. *Electrical Engineering & Electromechanics, 2,* 13–19. https://doi.org/10.20998/2074-272x.2020.2.02

13. Milykh, V. I., Shylkova, L. V. (2020). Experimental research of the three-phase physical model of the magnetic field inductor in the working mode when processing bulk material. *Bulletin of NTU "Kharkiv Polytechnic Institute" Series: Electrical Machines and Electromechanical Energy Conversion, 3 (1357),* 3–7. https://doi.org/10.20998/2409-9295.2020.3.01

14. Guo, Y., Zhu, J. G., Zhong, J., Lu, H., Jin, J. X. (2008). Measurement and Modeling of Rotational Core Losses of Soft Magnetic Materials Used in Electrical Machines: A Review. *IEEE Transactions on Magnetics, 44 (2),* 279–291. https://doi.org/10.1109/tmag.2007.911250

15. Prozorov, R., Kogan, V. G. (2018). Effective Demagnetizing Factors of Diamagnetic Samples of Various Shapes. *Physical Review Applied, 10 (1).* https://doi.org/10.1103/physrevapplied.10.014030

16. Mattei, J.-L., Floc'h, M. L. (2003). Percolative behaviour and demagnetizing effects in disordered heterostructures. *Journal of Magnetism and Magnetic Materials, 257 (2-3),* 335–345. https://doi.org/10.1016/s0304-8853(02)01232-5
17. Atallah, K., Howe, D. (1993). Calculation of the rotational power loss in electrical steel laminations from measured H and B. *IEEE Transactions on Magnetics, 29 (6),* 3547–3549. https://doi.org/10.1109/20.281225
18. Alatawneh, N., Pillay, P. (2011). Design of a novel test fixture to measure rotational core losses in machine laminations. *2011 IEEE Energy Conversion Congress and Exposition.* Phoenix, 433–440. https://doi.org/10.1109/ecce.2011.6063802
19. Polshchikov, G. A., Zhukov, P. B. (1978). A.Cv. na izobretenie SU 627848 A1. *Sposob kontrolia protcessov v apparate s vikhrevym sloem.* Published: 15.10.78, Bul. No. 38.

DOI: 10.15587/2706-5448.2025.347970

OPTIMIZATION OF PUBLIC BUILDING GLAZING ACCORDING TO ENERGY EFFICIENCY CRITERIA

page 57–63

Leonid Kosenko, *PhD Student, Department of Reinforced-Concrete and Masonry Structures, Ukrainian State University of Science and Technologies, Dnipro, Ukraine, e-mail: kosenko.leonid@365.pdaba.edu.ua, ORCID: https://orcid.org/0000-0002-8841-8318*

Olena Koval, *PhD, Associate Professor, Department of Reinforced-Concrete and Masonry Structures, Ukrainian State University of Science and Technologies, Dnipro, Ukraine, ORCID: https://orcid.org/0000-0001-7805-6811*

Yevhenii Yurchenko, *PhD, Associate Professor, Department of Reinforced-Concrete and Masonry Structures, Ukrainian State University of Science and Technologies, Dnipro, Ukraine, ORCID: https://orcid.org/0000-0002-9356-3261*

Artem Koval, *PhD Student, Department of Reinforced-Concrete and Masonry Structures, Ukrainian State University of Science and Technologies, Dnipro, Ukraine, ORCID: https://orcid.org/0009-0006-6989-5553*

Serhii Hryshyn, *PhD Student, Department of Reinforced-Concrete and Masonry Structures, Ukrainian State University of Science and Technologies, Dnipro, Ukraine, ORCID: https://orcid.org/0009-0006-0393-5671*

The object of research is a two-story office building. One of the problem areas in building envelopes is stained glass structures that do not meet modern energy efficiency requirements and have significant heat loss. The research aims to develop optimal design solutions for modernizing existing glazing, aimed at reducing heat loss while preserving the architectural appearance of the facade and the economic feasibility of implementing thermal renovation measures.

The research used a set of methods, namely the creation of a BIM model of the building, analysis of the thermal insulation properties of building envelopes, technical and economic comparison of thermal renovation options, and online calculation tools from window companies. The research results provided indicators of heat loss through the stained glass windows of the existing system and the proposed reconstruction options, as well as the amount of solar gain. Three options for replacing the stained glass windows were developed. One option involved the use of Rehau SYNEGO® MD-80 with 490 mm mullions and a reduction in the area of translucent structures. The heat loss savings are 56%, and the implementation cost is 3084 EUR, which is an acceptable indicator among the options considered. This is because the proposed option meets energy efficiency requirements and also takes into account the customer's restrictions on changing the architectural appearance of the facade by no more than 50%.

The proposed approach allows for a comprehensive assessment of the impact of the proposed measures on the energy balance of the building, taking into account architectural constraints and justifying an economically viable solution. Compared to traditional solutions for replacing stained glass windows based solely on thermal conductivity or standard facade solutions without taking into account the conditions of a specific object.

The results obtained can be used for implementation in similar objects in public and office buildings during reconstruction or new construction.

Keywords: energy efficiency, glazing, facade, thermal insulation, Building Information Model, heat loss, energy conservation, thermal renovation.

References

1. *Action Plan: Energy Efficiency in Buildings. Low Carbon Technology Partnerships Initiative* (2015). World Business Council for Sustainable Development. Available at: https://docs.wbcsd.org/2015/12/LCTPi-EEB-Action-Plan.pdf
2. Davis, A. (2018). *Neither a borrower nor a lender be: Energy efficiency decision-making among class B and C offices in Pittsburgh.* https://doi.org/10.31234/osf.io/z76xg
3. Ur Rehman, H., Heimonen, I., Vainio, T., Ramesh, R., Wallin, A. (2022). *Technical recommendations of the new built Nearly Zero Energy Building (NZEB) in Ukraine.* VTT. Available at: https://www.vttresearch.com/sites/default/files/2022-12/NZEB_Final_Workshop_VTT_Presentation.pdf
4. Primasetra, A., Larasati, D., Wonorahardjo, S. (2022). BIM Utilization in Improving Energy Efficiency Performance on Architectural Design Process: Challenges and Opportunities. *IOP Conference Series: Earth and Environmental Science, 1058 (1),* 012018. https://doi.org/10.1088/1755-1315/1058/1/012018
5. Fürtön, B., Nagy, B. (2022). BIM based hygrothermal modelling of building constructions. *Acta Polytechnica CTU Proceedings, 38,* 340–346. https://doi.org/10.14311/app.2022.38.0340
6. Erebor, E. M., Ibem, E. O., Ezema, I. C., Sholanke, A. B. (2021). Energy Efficiency Design Strategies in Office Buildings: A Literature Review. *IOP Conference Series: Earth and Environmental Science, 665 (1),* 012025. https://doi.org/10.1088/1755-1315/665/1/012025
7. Arends, I., Prinz, C., Abma, F. (2017). Job quality, health and at-work productivity. *OECD Social, Employment and Migration Working Papers, No. 195.* Available at: https://www.oecd.org/content/dam/oecd/en/publications/reports/2017/06/job-quality-health-and-at-work-productivity_e4c3283e/43ff6bdc-en.pdf
8. Kosenko, L., Koval, O., Yurchenko, E., Koval, A. (2023). Analysis of European regulatory requirements for near to zero energy consumption buildings and the possibility of implementation in Ukraine. *Ventilation, Illumination and Heat Gas Supply, 47,* 28–35. https://doi.org/10.32347/2409-2606.2023.47.28-35
9. Bondarenko, A., Yurchenko, E., Olena, K., Savytskyi, M. (2023). Comparative analysis of microclimate parameters of residential low-rise buildings with different heating systems. *Innovative technologies in construction, civil engineering and architecture, 2678.* https://doi.org/10.1063/5.0119318
10. Lyachovetskaya-Tokareva, M., Yurchenko, Y., Koval, O., Tymoshenko, O. (2023). Mathematical modeling of the refrigerating equipment in the air conditioning system during industrial energy audit. *Innovative technologies in construction, civil engineering and architecture, 2678.* https://doi.org/10.1063/5.0118991
11. Demydov, O. (2024). *Metody pidvyshchennia enerhoefektyvnosti ofisnoi budivli.* Kvalifikatsiina vypuskova robota. Available at: http://srd.pgasa.dp.ua:8080/xmlui/handle/123456789/13430
12. Demydov, O., Kosenko, L., Koval, O., Yurchenko, E. (2024). Research and simulation of an office lighting. *Ventilation, Illumination and Heat Gas Supply, 49,* 7–15. https://doi.org/10.32347/2409-2606.2024.49.7-15
13. *DSTU 9191:2022. Teploizoliatsiia budivel. Metody vyboru teploizoliatsiinoho materialu dlia uteplennia budivel* (2023). Tekhnichnyi komitet standartyzatsii TK 302 "Enerhoefektyvnist budivel i sporud". Available at: https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=98996
14. *DBN V.2.6-31:2021. Teplova izoliatsiia ta enerhoefektyvnist budivel* (2022). DP "Derzhavnyi naukovo-doslidnyi instytut budivelnykh konstruktsii". Available at: https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=98037
15. *DSTU 9190:2022. Enerhetychna efektyvnist budivel. Metod rozrakhunku enerhospozhyvannia pid chas opalennia, okholodzhennia, ventyliatsii, osvitlennia ta hariachoho vodopostachannia* (2023). Tekhnichnyi komitet standartyzatsii TK 302 "Enerhoefektyvnist budivel i sporud". Available at: https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=98995
16. *VEKA's online service for designing and calculating the energy efficiency of glazing.* Available at: https://windoplan.veka.com/
17. Energy Efficiency. *REHAU Window Solutions.* https://window.rehau.com/uk-en/why-choose-pvcu/energy-efficiency

ISSN-L 2664-9969; E-ISSN 2706-5448

ELECTRICAL ENGINEERING AND INDUSTRIAL ELECTRONICS

DOI: 10.15587/2706-5448.2025.344863

ENERGY CONVERSION EFFICIENCY IN THE ELECTROMECHANICAL SYSTEM WITH MAGNETIC GEAR OF PASSENGER ELECTRIC TRANSPORT ROLLING STOCK

pages 64–74

Mykola Ostroverkhov, *Doctor of Technical Sciences, Professor, Department of Theoretical Electrical Engineering, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Kyiv, Ukraine, ORCID: https://orcid.org/0000-0002-7322-8052*

Liudmyla Spinul, *PhD, Associate Professor, Department of Theoretical Electrical Engineering, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Kyiv, Ukraine, ORCID: https://orcid.org/0000-0002-4234-6072*

Heorhii Veshchykov, *PhD Student, Department of Theoretical Electrical Engineering, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Kyiv, Ukraine, e-mail: veschikov98@gmail.com, ORCID: https://orcid.org/0009-0002-0606-9765*

The object of research is electromechanical processes in the traction electric drive of the rolling stock of passenger electric transport under the action of strong and short-term moments of disturbance during acceleration, movement at a steady speed and deceleration.

The problem under consideration was to determine the influence of the parameters of the magnetic reducer on reducing the effect of external disturbances on the electromechanical system of the rolling stock of the metro. The analysis was carried out on the basis of a comparison of a typical traction electric drive with a mechanical reducer and the proposed electric drive with a magnetic reducer. This reducer transmits the moving moment to the wheel pairs without mechanical contact, but at the same time causes an elastic-viscous connection between its input and output shafts.

A comparison of the behavior of the electromechanical system using a typical mechanical reducer and the proposed magnetic reducer is presented. The influence on the efficiency of energy conversion of the parameters of the magnetic reducer, in particular the magnetic stiffness and the damping coefficient, is investigated. During the research, differences were found in the dependences of the amplitude of moments, the period of natural oscillations, and the time of damping of the transient process for two types of gearboxes. With a stiffness of the magnetic gearbox of 5000 Nm/rad, the amplitude of the moment decreased by 59% compared to the mechanical gearbox. The period of natural oscillations decreased by 62%, and the damping of the transient process increased by 59%. The research results showed that the rational choice of the parameters of the magnetic gearbox allows to increase the dynamic stability of the electric drive to short-term disturbances. At the same time, shock loads on the motor shaft and the amplitude of torque fluctuations are reduced. This is especially relevant for traction systems of transport operating in conditions of uneven resistance to movement.

The practical value of the research results lies in the possibility of improving the efficiency of energy conversion and the quality indicators of control of the traction electric drive of the rolling stock of passenger electric transport. This research will be useful for scientists and companies specializing in the field of rolling stock of passenger electric transport.

Keywords: efficiency, magnetic transmission, reducer, damping, stiffness, electric transport, traction electric drive, torque.

References

1. Atallah, K., Wang, J., Calverley, S. D., Duggan, S. (2012). Design and Operation of a Magnetic Continuously Variable Transmission. *IEEE Transactions on Industry Applications, 48 (4),* 1288–1295. https://doi.org/10.1109/tia.2012.2199451
2. Tlali, P. M., Wang, R.-J., Gerber, S. (2014). Magnetic gear technologies: A review. *2014 International Conference on Electrical Machines (ICEM).* Berlin, 544–550. https://doi.org/10.1109/icelmach.2014.6960233
3. Atallah, K., Howe, D. (2001). A novel high-performance magnetic gear. *IEEE Transactions on Magnetics, 37 (4),* 2844–2846. https://doi.org/10.1109/20.951324
4. Atallah, K., Rens, J., Mezani, S., Howe, D. (2008). A Novel "Pseudo" Direct-Drive Brushless Permanent Magnet Machine. *IEEE Transactions on Magnetics, 44 (11),* 4349–4352. https://doi.org/10.1109/tmag.2008.2001509
5. Jing, L., Chen, J., Huang, Z. (2019). Analysis of Magnetic Field of Magnetic Gear during Overload. *2019 4th International Conference on Intelligent Green Building and Smart Grid (IGBSG).* Hubei, 557–558. https://doi.org/10.1109/igbsg.2019.8886243
6. Wang, J., Atallah, K. (2009). Modeling and control of 'pseudo' direct-drive brushless permanent magnet machines. *2009 IEEE International Electric Machines and Drives Conference.* Miami, 870–875. https://doi.org/10.1109/iemdc.2009.5075306
7. Bouheraoua, M., Wang, J., Atallah, K. (2014). Speed Control for a Pseudo Direct Drive Permanent-Magnet Machine With One Position Sensor on Low-Speed Rotor. *IEEE Transactions on Industry Applications, 50 (6),* 3825–3833. https://doi.org/10.1109/tia.2014.2322139
8. O'Sullivan, T. M., Bingham, C. M., Schofield, N. (2006). High-Performance Control of Dual-Inertia Servo-Drive Systems Using Low-Cost Integrated SAW Torque Transducers. *IEEE Transactions on Industrial Electronics, 53 (4),* 1226–1237. https://doi.org/10.1109/tie.2006.878311
9. Zhang, G., Furusho, J. (1999). Speed control of two-inertia system by PI/PID control. *Proceedings of the IEEE 1999 International Conference on Power Electronics and Drive Systems. PEDS'99 (Cat. No.99TH8475).* Hong Kong, 1, 567–572. https://doi.org/10.1109/peds.1999.794627
10. Montague, R. G., Atallah, K., Bingham, C. M. (2010). Characterisation and modelling of magnetic couplings and gears for servo control systems. *5th IET International Conference on Power Electronics, Machines and Drives (PEMD 2010).* Brighton, 232–232. https://doi.org/10.1049/cp.2010.0188
11. Desvaux, M., Le Goff Latimier, R., Multon, B., Sire, S., Ben Ahmed, H. (2016). Analysis of the dynamic behaviour of magnetic gear with nonlinear modelling for large wind turbines. *2016 XXII International Conference on Electrical Machines (ICEM).* Lausanne, 1332–1338. https://doi.org/10.1109/icelmach.2016.7732697
12. *PDD® High Torque Traction Motor.* Available at: https://www.magnomatics.com/_files/ugd/afb904_3f9af3d122ce4f96a450da2a89a1a103.pdf
13. Yang, Z., Shang, F., Brown, I. P., Krishnamurthy, M. (2015). Comparative Study of Interior Permanent Magnet, Induction, and Switched Reluctance Motor Drives for EV and HEV Applications. *IEEE Transactions on Transportation Electrification, 1 (3),* 245–254. https://doi.org/10.1109/tte.2015.2470092
14. Bozhko, S., Dymko, S., Kovbasa, S., Peresada, S. M. (2017). Maximum Torque-per-Amp Control for Traction IM Drives: Theory and Experimental Results. *IEEE Transactions on Industry Applications, 53 (1),* 181–193. https://doi.org/10.1109/tia.2016.2608789