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IMPROVEMENT OF THE METHOD OF CALCULATION OF MECHANICAL CHARACTERISTICS OF A TRACTION MOTOR OF DIRECT CURRENT WITH COMBINED EXCITATION

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The object of the study is the process of appearing an electromagnetic moment in traction motors of combined excitation of a trolleybus at synchronous inclusion of both components of the excitation system. This process is formally presented as mechanical characteristics – dependence of an electromagnetic moment of the motor from excitation currents.

One of most problem points is to determine the influence of excitation currents of the series and separate winding on an electromagnetic moment of the motor as a continuous dependence that allows to create a system of managing the traction drive with DC-DC excitation transformer. Peculiarities of the motor magnetic system are also taken into account.

During the study there was used the method of finite elements in the flat-parallel target setting of calculating moments by the results of calculating the magnetic field with the further regression analysis of results of digital experiments using Chebyshev polynomials on the set of equidistant points.

There was received the continuous dependence of an electromagnetic moment from excitation currents as a polynomial that can be used both at creating managing systems DC-DC by the excitation transformer and at modeling operation modes of the traction drive as a whole. It is connected with the fact that the offered polynomial type has a continuous type dependency and its derivatives at all possible values of currents at the drive work. According to the results of the regression analysis, the maximal deviation of calculated dependencies doesn't exceed 0.052, and mean deviation is no more 0.041. It proves the adequacy of the received dependencies to the results of the digital experiment on determining an electromagnetic moment.

Due to it, there is provided the possibility of modeling operation modes of the traction drive based on the motor with combined excitation and DC-DC transformer. The managing system parameters, received by modeling results, allow to raise energetic characteristics of trolleybuses. Comparing with analogous known systems, it provides more rational use of electric energy on thrust of the rolling stock.

Keywords: mechanical characteristics, traction drive, combined excitation, method of finite elements.

References

1. Liubarskyi, B. H. (2014). *Teoretychni osnovy dlia vyboru ta otsinky perspektyvnykh system elektromekhanichnoho peretvorennia enerhii elektrorukhomoho skladu*. Kharkiv: Natsionalnyi tekhnichnyi universytet «Kharkivskyi politekhnichnyi instytut», 368.
2. Pavlenko, T., Shavkun, V., Petrenko, A. (2017). Ways to improve operation reliability of traction electric motors of the rolling stock of electric transport. *Eastern-European Journal of Enterprise Technologies, 5 (8 (89)),* 22–30. doi: https://doi.org/10.15587/1729-4061.2017.112109
3. Pan, L., Zhang, C. (2016). An Integrated Multifunctional Bidirectional AC/DC and DC/DC Converter for Electric Vehicles Applications. *Energies, 9 (7),* 493. doi: https://doi.org/10.3390/en9070493
4. Brazis, V., Kroics, K., Grigans, L. (2014). Scientific Laboratory Platform for Testing the Electric Vehicle Equipped with DC Drive. *Latvian Journal of Physics and Technical Sciences, 51 (5),* 56–64. doi: https://doi.org/10.2478/lpts-2014-0030
5. Kharchenko, V. F., Daleka, V. Kh., Andriychenko, V. P., Kostenko, I. O. (2010). Pat. No. 60109 UA. *Sposib oslablennia polia tiahovoho elektrodvyhuna zmishanoho zbudzhennia*. MPK (2006.01) N02R 7/06. No. u201013973; declareted: 23.11.2010; published: 10.06.2011, Bul. No. 11.
6. Andriychenko, V. P., Zakurdai, S. O., Kostenko, I. O. (2014). Improvement of the method used for control of starting direkt-currentrailway motor. *Eastern-European Journal of Enterprise Technologies, 1 (8 (67)),* 32–35. doi: https://doi.org/10.15587/1729-4061.2014.20123
7. Ravino, V. V., Sacukevich, V. N., Galyamov, P. M. (2007). Approksimaciya krivoy namagnichivaniya tyagovyh elektrodvigateley trolleybusov. Energetika. *Izvestiya vysshih uchebnyh zavedeniy i energeticheskih ob'edineniy SNG, 1,* 27–33.
8. Lyubarskiy, B. G. (2000). *Modelirovanie i razrabotka kombinirovannogo vozbuzhdeniya svarochnyh generatorov postoyannogo toka s cel'yu uluchsheniya ih tekhniko-ekonomicheskih pokazateley*. Kharkiv, 170.
9. *Finite Element Method Magnetics: HomePage*. Available at: http://www.femm.info/wiki/HomePage
10. Meeker, D. (2016). Series-wound heteropolar inductor motor for automotive applications. *2016 IEEE Transportation Electrification Conference and Expo (ITEC)*. doi: https://doi.org/10.1109/itec.2016.7520203
11. Ryabov, E. S. (2011). *Bezreduktorniy tyagoviy privod na osnove reaktivnogo induktornogo dvigatelya s aksial'nym magnitnym potokom dlya skorostnogo elektropodvizhnogo sostava*. Kharkiv, 162.
12. Riabov, E. S., Liubarskyi, B. H., Yakunyn, D. Y., Ziuzyn, D. Yu. (2010). Modelyrovanye tiahovoho bezreduktornoho pryvoda na osnove ynduktornoho dvyhatelia s aksyalnym mahnytnym potokom. *Visnyk Natsionalnoho tekhnichnoho universytetu «Kharkivskyi politekhnichnyi instytut», 57,* 243–251.
13. Lyubarskiy, B. G., Yakunin, D. I. (2011). Imitacionnoe modelirovanie mekhanizma naklona kuzova s lineynym elektromekhanicheskim preobrazovatelem. *MATLAB:* materialy V Mezhdunarodnoy nauchnoy konferencii. Kharkiv: BET, 425–436.

MECHANICS

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DEVELOPMENT OF METHOD OF INCREASING ACCURACY OF MEASURING ANGULAR VELOCITY AND ACCELERATION OF GYROSTABILIZED PLATFORM

page 11–16

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Modern mobile objects have significantly higher velocities, they are significantly more overloaded and uncontrollable mechanical disturbances (shocks, vibrations). Therefore, the requirements for the accuracy of means and methods for measuring the above-defined mechanical values of the instrument navigation complex have become much higher. However, the imperfection of the element base, the absence of new modern sensitive elements, the lack of the use of a new improved shock protection system, the lack of modern algorithmic methods do not allow to significantly improve accuracy and improve tactical and technical characteristics.

The object of research in this work is the process of measuring the angular velocity and acceleration of a gyrostabilized platform.

Ensuring the accuracy of the arms stabilizer is the most important modern problem, the solution of which ensures the security of Ukraine. According to tactical characteristics, the new weapon stabilizer expands combat capabilities of armored vehicles due to more precise guidance and stabilization on the target, facilitates the crew's ability to control the tower.

Instrumental weapon stabilizer complexes are designed for stabilized guidance and tracking in the horizontal and vertical planes of surface, air and surface targets. The use of a modern element base has significantly improved the characteristics of the entire range of the weapon stabilizer. According to the technical characteristics of

the arms stabilizer, it expands the combat capabilities of armored vehicles through more precise guidance and stabilization on the target, facilitates the crew's ability to control the tower. And also does not require redirection to the same goal after the shot.

In this paper, an algorithm is considered that is applied when adjusting the position of the implement relative to the target during rapid joint movement of the tower and the machine. The algorithm is calculated in the mathematical block of the stabilization system. The algorithm is based on a mathematical analysis of the theory of motion of gyroscopes and improved from previous ones by supplementing the equation of motion. The formula is derived in the analytical form for its further application in the mathematical blocks of the stabilization system and calculations are given, as a result of which a mathematical model is obtained. If this mathematical model is introduced into the algorithmic block of the stabilization system, this will improve the accuracy of stabilization.

The conclusions analyze the results and give recommendations on the application of the method.

Keywords: weapon stabilizer, gyrostabilized platform, angular velocity measurements, acceleration measurements.

References

1. Darestani, M. R., Nikkhah, A. A., Sedigh, A. K. (2013). H∞/Predictive output control of a three-axis gyrostabilized platform. *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering, 228 (5),* 679–689. doi: http://doi.org/10.1177/0954410013493237
2. Pan, S., Wu, Y., Zhang, J., Zhou, S., Zhu, H. (2018). Modeling and control of a 2-degree-of-freedom gyro-stabilized platform driven by ultrasonic motors. *Journal of Intelligent Material Systems and Structures, 29 (11),* 2324–2332. doi: http://doi.org/10.1177/1045389x18770739
3. Hilkert, J. (2008). Inertially stabilized platform technology Concepts and principles. *IEEE Control Systems, 28 (1),* 26–46. doi: http://doi.org/10.1109/mcs.2007.910256
4. Bredenkamp, A. F. L. (2007). *Development and control of 3-axis stabilized platform.* Matieland: Departament of Electrical and Electronic Engineering Univercity of Stellenbosch, 95.
5. Savage, P. G. (2018). Improved strapdown inertial measurement unit calibration procedures. *2018 IEEE/ION Position, Location and Navigation Symposium (PLANS).* doi: http://doi.org/10.1109/plans.2018.8373422
6. Malyutin, D. M. (2018). Miniature gyroscopic orientation system for unmanned aerial vehicle. *2018 25th Saint Petersburg International Conference on Integrated Navigation Systems (ICINS).* doi: http://doi.org/10.23919/icins.2018.8405916
7. Tadano, S., Takeda, R., Miyagawa, H. (2013). Three Dimensional Gait Analysis Using Wearable Acceleration and Gyro Sensors Based on Quaternion Calculations. *Sensors, 13 (7),* 9321–9343. doi: http://doi.org/10.3390/s130709321
8. Bezvesilna, O. M., Tsiruk, V. H., Kvasnikov, V. P., Chikovani, V. V. (2014). *Systemy navedennia ta stabilizatsii ozbroiennia.* Zhytomyr, 176.
9. Korobiichuk, I., Bezvesilna, O., Tkachuk, A., Chilchenko, T., Nowicki, M., Szewczyk, R. (2016). Design of Piezoelectric Gravimeter for Automated Aviation Gravimetric System. *Journal of Automation, Mobile Robotics & Intelligent Systems, 10 (1),* 43–47. doi: http://doi.org/10.14313/jamris_1-2016/6
10. Korobiichuk, I., Bezvesilna, O., Kachniarz, M., Tkachuk, A., Chilchenko, T. (2016). Two-Channel MEMS Gravimeter of the Automated Aircraft Gravimetric System. *Advances in Intelligent Systems and Computing,* 481–487. doi: http://doi.org/10.1007/978-3-319-48923-0_51
11. Mel'nik, V. N., Karachun, V. V. (2004). Determining Gyroscopic Integrator Errors Due to Diffraction of Sound Waves. *International Applied Mechanics, 40 (3),* 328–336. doi: http://doi.org/10.1023/b:inam.0000031917.13754.2a
12. Pavlov, V. A. (1970). *The Gyroscopic Effect: Its Manifestations and Uses.* Defense Technical Information Center.
13. Bezvesilna, O. M., Tsiruk, V. H., Maliarov, S. P. et. al. (2016). *Naukovi osnovy pobudovy pretsyziinoho chutlyvoho elementu kompleksu stabilizatora ozbroiennia lehkoi bronovanoi tekhniky.* Kyiv: NPO «Priority», 234.
14. Pel'por, D. S. (1986). Giroskopicheskie sistemy. *Teoriya giroskopov i girostabilizatorov.* Moscow: Vysshaya shkola, 423.
15. Korobiichuk, I., Bezvesilna, O., Tkachuk, A., Chilchenko, T., Nowicki, M., Szewczyk, R. (2016). Design of Piezoelectric Gravimeter for Automated Aviation Gravimetric System. *Journal of Automation, Mobile Robotics & Intelligent Systems, 10 (1),* 43–47. doi: http://doi.org/10.14313/jamris_1-2016/6
16. Korobiichuk, I., Koval, A., Nowicki, M., Szewczyk, R. (2016). Investigation of the Effect of Gravity Anomalies on the Precession Motion of Single Gyroscope Gravimeter. *Solid State Phenomena, 251,* 139–145. doi: http://doi.org/10.4028/www.scientific.net/ssp.251.139
17. Korobiichuk, I., Bezvesilna, O., Tkachuk, A., Nowicki, M., Szewczyk, R. (2016). Piezoelectric Gravimeter of the Aviation Gravimetric System. *Advances in Intelligent Systems and Computing.* Cham: Springer, 753–761. doi: http://doi.org/10.1007/978-3-319-29357-8_65
18. Koval, A., Irigoyen, E. (2016). Mobile Wireless System for Outdoor Air Quality Monitoring. *Advances in Intelligent Systems and Computing.* Cham: Springer, 345–354. doi: http://doi.org/10.1007/978-3-319-47364-2_33
19. Tsyporenko, V., Tsyporenko, V. (2016). Development of direct method of direction finding with two-dimensional correlative processing of spatial signal. *Eastern-European Journal of Enterprise Technologies, 6 (9 (84)),* 63–70. doi: http://doi.org/10.15587/1729-4061.2016.85599

ELECTRICAL ENGINEERING AND INDUSTRIAL ELECTRONICS

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EXPERIMENTAL STUDY AND MODELING OF PARTIAL DISCHARGE DETECTION SYSTEM

page 17–22

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The object of research is an electrical system for detecting partial discharges in a sample of high voltage equipment insulation. To evaluate the insulation state of electrical equipment, various methods for detecting partial discharges have been developed and continue to be improved. The role of modeling, virtual experiment and virtual laboratory lessons has recently increased in all areas of engineering.

At the same time, some aspects of modeling the electrical systems for partial discharges detection are practically not studied sufficiently. Modeling is an important additional kind of practical training for a further work with measuring and testing equipment in professional activity. The aim of research is determination of the possibility of using an equivalent circuit simulation model in the research and educational process as an analogue of a system for measuring the characteristics of partial discharges.

To measure the characteristics of partial discharges in samples of high-voltage insulation, a special experimental test stand was assembled. The stand allows testing the physical model of insulation by applying alternating current high voltage. To visualize individual partial discharge pulses on an oscilloscope, a high-pass filter was designed and assembled that suppresses the 50 Hz main frequency voltage, and is a 4th order Butterworth filter. The oscillogram of partial discharge pulses that occur near a surface of high-voltage electrode in an insulating gap with an electrical cardboard was obtained. It has been experimentally established that partial discharge impulses of different amplitudes arise in the insulating gap with an explicit polarity effect. The experimental oscillogram was adopted as a sample, to which the oscillogram should approach in the simulation. The electrical equivalent circuit for insulation is represented by a traditional three-capacitive equivalent circuit for a dielectric with a gas cavity.

As a result of the research it was established that it is possible to obtain results close to those observed in the physical experiment. The possibility of modeling partial discharges in a dielectric in the presence of two or more gas cavities is shown.

Keywords: circuit simulation, partial discharge, high-pass filter, Butterworth filter.

References

1. Vdoviko, V. P. (2007). *Chastichnye razriady v diagnostirovanii vysokovol'tnogo oborudovaniia*. Novosibirsk: Nauka, 155.
2. Gulski, E. (1995). Digital analysis of partial discharges. *IEEE Transactions on Dielectrics and Electrical Insulation, 2 (5),* 822–837. doi: http://doi.org/10.1109/94.469977
3. Gemant, A., Philippoff, W. (1932). Die Funkenstrecke mit Vorkondensator. *Zeitschrift für Technische Physik, 13 (9),* 425–430.
4. Lemke, E. (2012). A critical review of partial-discharge models. *IEEE Electrical Insulation Magazine, 28 (6),* 11–16. doi: http://doi.org/10.1109/mei.2012.6340519
5. Deng, J., Wang, M., Zhou, Y., Zhou, Z., Zhang, Y., Zhang, L., Liu, X. (2016). Partial discharge characteristics of uniform gap in oil-impregnated paper insulation under switching impulse voltage. *IEEE Transactions on Dielectrics and Electrical Insulation, 23 (6),* 3584–3592. doi: http://doi.org/10.1109/tdei.2016.005508
6. *Micro-Cap 11. Electronic Circuit Analysis Program. Reference Manual* (2014). Sunnyvale: Spectrum Software, 1040. Available at: http://www.spectrum-soft.com/down/rm11.pdf
7. Trotsenko, Y., Brzhezitsky, V., Protsenko, O., Chumack, V., Haran, Y. (2017). Simulation of partial discharges under influence of impulse voltage. *Technology Audit and Production Reserves, 1 (1 (39)),* 36–41. doi: http://doi.org/10.15587/2312-8372.2018.123309
8. Trotsenko, Y., Brzhezitsky, V., Protsenko, O., Chumack, V., Haran, Y. (2017). Effect of voltage harmonics on pulse repetition rate of partial discharges. *Technology Audit and Production Reserves, 2 (1 (40)),* 37–44. doi: http://doi.org/10.15587/2312-8372.2018.126626
9. Gunawardana, S. D. M. S., Kanchana, A. A. T., Wijesingha, P. M., Perera, H. A. P. B., Samarasinghe, R., Lucas, J. R. (2015). A Matlab Simulink model for a partial discharge measuring system. *Electrical Engineering Conference*, 29–34.
10. Pahomov, A. I. (2005). *Metody i sredstva diagnostiki izoliatsii asinhronnyh dvigatelei sel'skohoziaistvennogo proizvodstva na osnove chastichnyh razriadov.* Krasnodar, 32.
11. Kolev, N. P., Danikas, M. G., Gadjeva, E. D., Gourov, N. R. (1999). Development of partial discharge model, simulation and measurement. *1999 Conference on Electrical Insulation and Dielectric Phenomena*. Austin, 214–217. doi: http://doi.org/10.1109/ceidp.1999.804629
12. GOST 20074-83. Electrical equipment and installations. Method measurements of partial discharge characteristics. (1983). Moscow: Izdatel'stvo standartov, 22.
13. IEC 60270:2000. High-voltage test techniques – Partial discharge measurements. (2000). Geneva: IEC Central Office, 99.
14. Illias, H. A., Chen, G., Lewin, P. L. (2009). Modelling of Partial Discharge Activity in Different Spherical Cavity Sizes and Locations within a Dielectric Insulation Material. *Proceedings of the 9th International Conference on Properties and Applications of Dielectric Materials*. Harbin, 485–488. doi: http://doi.org/10.1109/icpadm.2009.5252384
15. Iossel, Yu. Ya., Kochanov, E. S., Strunskiy, M. G. (1981). *Raschet elektricheskoy emkosti*. Leningrad: Energoizdat, 288.
16. Makarov, E. F.; Goryunov, I. T., Lyubimova, A. A. (Eds.) (1999). *Spravochnik po elektricheskim setyam 0.4-35 kV*. Vol. 1. Moscow: Papirus Pro, 608.

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ANALYSIS AND GENERALIZATION OF THE RESULTS OF AN EXPERIMENTAL RESEARCH OF THE RECHARGEABLE BATTERIES OF SELF-GUIDED ELECTRIC TORPEDO CET-65 (USSR) IN POST-GUARANTEE TERMS OF EXPLOITATION

page 23–29

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The object of research is the process of changing the electrical and tactical and technical characteristics of silver-zinc torpedo batteries during their post-warranty storage.

The subject of research is the technical gerontology of electrotechnical systems, namely silver-zinc storage batteries of the self-guided electric torpedo CET-65 (USSR).

Available in service silver-zinc torpedo batteries are on post-warranty storage terms: from 30 years and more. The changes in their parameters that passed during this period, as well as the gerontological processes taking place in them, have been little studied. In conditions of forced operation on post-warranty storage terms, there is an urgent need to monitor their condition. Proceeding from this, the identification of regularities in the change in the electrotechnical characteristics of silver-zinc torpedo accumulator batteries from their storage times and determining the impact of these changes on the main tactical and technical characteristics of the torpedo is an important scientific and applied problem.

The model of life cycle of silver-zinc batteries is analyzed. This allows to predict the changes in the basic electrical characteristics from the time of their storage, as well as the impact of these changes on the main tactical and technical characteristics of the torpedo. The dependences of the effect of the torpedo storage period for more than 20 years on the intensity of the decrease in its speed and the range of its course are determined. It is found that these indicators deteriorate to 20 % and 17 %, respectively. Correction of the model of the life cycle of the torpedo battery is carried out. It is established that taking into account the operation of the automatic guidance system, the period of expedient operation of the torpedo battery should not exceed 16 years. Based on the gerontological changes in the power supply sources of the torpedo battery, a method for correcting torpedo firing is proposed. This will compensate for the increase in the scattering in the lateral direction and in range, as well as the increase in the angle of the calculated point of the torpedo encounter with the target. In turn, this will allow performing training and combat missions using the available torpedoes of post-warranty storage periods.

Keywords: torpedoes of post-warranty storage periods, silver-zinc storage batteries, gerontological changes.

References

1. Anipko, O. B., Shheptsov, O. V. (2014). Gerontologicheskie izmeneniya serebryano-tsinkovykh akkumulyatornykh batarey torpedy SET-65 v protsesse dlitel'nogo khraneniya. *Intehrovani tekhnolohii ta enerhozberezhennia, 4,* 58–64.
2. *Rukovodstvo po khraneniyu i remontu protivolodochnogo, torpednogo, minnogo, protivominnogo i protivopodvodno-diversionnogo oruzhiya i vooruzheniya*. (1986). Moscow: Voennoe izdatel'stvo MO SSSR, 279.
3. Analiz ta pidsumky ekspluatatsii ozbroiennia ta viiskovoi tekhniky Zbroinykh syl Ukrainy u 2011 rotsi. (2012). *Ozbroiennia Zbroinykh syl Ukrainy*. Kyiv, 67.
4. Rogozhnikov, K., Kuz'mitskiy, M. (2002). Vypuskniki fakul'teta morskogo priborostroeniya – sozdateli torped. *Za kadry verfyam, 9,* 4.
5. Anipko, O. B., Mulenko, A. O. et. al. (2010). Problema zhivuchesti stvolov strelkovogo oruzhiya pri primenenii boepripasov poslegarantiynykh srokov khraneniya. *Intehrovani tekhnolohii ta enerhozberezhennia, 3,* 80–83.
6. Anipko, O. B., Mulenko, A. O., Demchenko, A. A. (2013). Eksperimental'noe issledovanie iznosa stvola 5,45 mm avtomata Kalashnikova AK-74 pri strel'be boepripasami dlitel'nykh srokov khraneniya. *Intehrovani tekhnolohii ta enerhozberezhennia, 2,* 121–126.
7. Johnston, A. (2005). *Understanding and Predicting Gun Barrel Erosion*. Edinburgh: Department of Defence Australian Government, 52.
8. Biryukov, A., Gurnovich, A., Biryukov, I. (2017). Experimental research of wear intensitivity of 9mm pistol barrel with the use of long-term storage ammunition. *Technology Audit and Production Reserves, 2 (2 (34)),* 48–54. doi: http://doi.org/10.15587/2312-8372.2017.100467
9. Anipko, O. B., Demchenko, A. A. (2014). Eksperimental'noe issledovanie ballisticheskikh kharakteristik 120 mm minometa pri primenenii metatel'nykh zaryadov dlitel'nykh srokov khraneniya. *Intehrovani tekhnolohii ta enerhozberezhennia, 2,* 61–70.
10. Anipko, O. B., Borisyuk, M. D., Busyak, Yu. M. (2011). Eksperimental'noe issledovanie zhivuchesti stvola gladkostvol'noy pushki. *Intehrovani tekhnolohii ta enerhozberezhennia, 1,* 28–31.
11. Anipko, O. B., Verteletskiy, V. F. (2013). Izmenenie fiziko-khimicheskikh svoystv porokhovogo zaryada i nachal'noy skorosti artilleriyskikh boepripasov morskoy nomenklatury kalibrov 25/80 i 30/54. *Intehrovani tekhnolohii ta enerhozberezhennia, 2,* 74–80.
12. Anipko, O. B., Redin, N. N., Shheptsov, O. V. (2013). Eksperimental'noe issledovanie akkumulyatornykh batarey elektricheskikh torped, nakhodyashhikhsya na poslegarantiynykh etapakh ekspluatatsii. *Intehrovani tekhnolohii ta enerhozberezhennia, 2,* 3–8.
13. Anipko, O. B., Shheptsov, O. V. (2013). Izmenenie osnovnykh energeticheskikh pokazateley akkumulyatornykh batarey torped na poslegarantiynykh etapakh ekspluatatsii i ikh vliyanie na osnovnye takticheskie kharakteristiki torpednogo oruzhiya. *Zbirnyk naukovykh prats AVMS imeni P. S. Nakhimova, 3 (15),* 9–15.
14. Alyanak, E., Grandhi, R., Penmetsa, R. (2006). Optimum design of a supercavitating torpedo considering overall size, shape, and structural configuration. *International Journal of Solids and Structures, 43 (3-4),* 642–657. doi: http://doi.org/10.1016/j.ijsolstr.2005.05.040
15. Alyanak, E., Venkayya, V., Grandhi, R., Penmetsa, R. (2005). Structural response and optimization of a supercavitating torpedo. *Finite Elements in Analysis and Design, 41 (6),* 563–582. doi: http://doi.org/10.1016/j.finel.2004.10.005
16. Polyakov, L. (2005). *Aging stocks of ammunition and SALW in Ukraine: risks and challenges*. Bonn International Center for Conversion, 66.
17. Praveen, D. (2014). *Analysis the world's deadliest torpedoes*. Naval technology. Available at: https://www.naval-technology.com/features/featurethe-worlds-deadliest-torpedoes-4286162/. Last accessed: 10.03.2018
18. Torpedoes and the Next Generation of Undersea Weapons. (2002). *Undersea warfare magazine*. Available at: https://www.public.navy.mil/subfor/underseawarfaremagazine/Issues/Archives/issue_14/torpedoes.html. Last accessed: 10.03.2018
19. Anipko, O. B., Khaykov, V. L., Shheptsov, O. V. (2013). Prognozirovanie izmeneniya energeticheskikh pokazateley akkumulyatornykh batarey elektricheskikh torped v zavisimosti ot srokov ikh khraneniya. *Zbirnik naukovikh prats' AVMS imeni P. S. Nakhimova, 2 (14),* 14–19.
20. *Otchet issledovaniya batarey A-187M, posle dlitel'nogo khraneniya i opredelenie vozmozhnosti ikh ispol'zovaniya*. (2001). OAO NPF «Luganskiy akkumulyator-1», 7.

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ANALYSIS OF DISTRIBUTION LAWS OF INSULATION INDICATORS OF HIGH-VOLTAGE OIL-FILLLED BUSHINGS OF HERMETIC AND NON-HERMETIC EXECUTION

page 30–39

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The object of research is the distribution laws of capacitor-type insulation values that were obtained during preventive tests for both serviceable and defective high-voltage bushings of 110 kV of hermetic and non-hermetic execution. One of the most problematic areas is insufficient knowledge and lack of justification of the laws for distributing these preventive tests of insulation of bushings.

In the course of the research, a comprehensive approach to the solution of the problems was used, including probability theory and statistical analysis, analysis of world experience and a logical approach. In the long term, the results are expected to be extended to the bushing of other types having similar problems in the diagnosis of the condition.

The method of statistical processing of the results of periodic tests of high-voltage bushings is proposed, which allows to form arrays with homogeneous values of indicators in conditions of limited measurement information. It is established that for the bushings of hermetic and non-hermetic execution, the insulation values for both the serviceable and faulty state can be described by the Weibull distribution. It is established that the distribution densities for serviceable and faulty state of high-voltage bushings intersect, and therefore it is impossible to select the maximum permissible values of insulation parameters that would not give erroneous solutions. The maximum permissible values of the insulation indices of high-voltage oil-filled bushings are proposed using statistical methods and taking into account the most significant operational factors. It is shown that for high-voltage bushings of the same execution there is a shift in mathematical expectations, which is due to the difference in operating time and different load factors of transformers. This circumstance must be taken into account when adjusting the maximum permissible values of the insulation indices of high-voltage bushings.

The use of the developed algorithms and procedures of mathematical statistics in the problems of diagnosing high-voltage bushings contribute to improving expert judgment and decision-making.

Keywords: high-voltage bushings, insulation indicators, statistical criteria, variance analysis, consent criteria, Weibull's distribution.

References

1. Feilat, E. A. (2013). Analysis of the Root Causes of Transformer Bushing Failures. *International Journal of Computer, Electrical, Automation, Control and Information Engineering, 7,* 791–796.
2. Anglhuber, M., Velasquez, J. L. (2017). Contreras Dispersing the clouds – gain clear insight into your bushings using advanced

diagnostics method. *Transformer Magazine*. Special Edition: Bushing, 126–132.
3. Septyani, H. I., Arifianto, I., Purnomoadi, A. P. (2011). High voltage transformer bushing problems. *Proceedings of the 2011 International Conference on Electrical Engineering and Informatics*. doi: http://doi.org/10.1109/iceei.2011.6021566
4. Metwally, I. (2011). Failures, Monitoring and New Trends of Power Transformers. *IEEE Potentials, 30 (3),* 36–43. doi: http://doi.org/10.1109/mpot.2011.940233
5. Kassikhin, S. D., Sipilkin, K. G., Slavinskiy, A. Z., Ustinov, V. N., Pintal, Yu. S., Vereshhagin, M. B. (2010). *Otsenka effektivnosti i tselesoobraznosti diagnostiki vysokovol'tnykh vvodov na osnove opyta ekspluatatsii*. Ekaterinburg: Izdatel'skiy dom «Avtograf», 232.
6. Rubanenko, O. Ye., Humeniuk, O. I. (2011). *Vysokovoltni vvody. Konstruktsiia, ekspluatatsiia, diahnostyka i remont*. Vinnytsia: VNTU, 183.
7. Sedunin, A. M., Chalov, I. A., Sidel'nikov, L. G. (2011). Klassifikatsiya vysokovol'tnykh vvodov silovykh transformatorov i problemy ikh ekspluatatsii na predpriyatiyakh gornoy promyshlennosti. *Gornoe oborudovanie i elektromekhanika, 12,* 24–30.
8. L'vov, M. Yu. (2000). Kolloidno-dispersnye protsessy v vysokovol'tnykh germetichnykh vvodakh transformatorov. *Elektricheskie stantsii, 4,* 49–52.
9. Snetkova, O. V. (2004). Opyt diagnostiki maslonapolnennykh vvodov 110–500 kV v OAO «Mosenergo». *Elektro, 2,* 39–42.
10. Komarov, V. I., Lushin, A. N., Osotov, V. N., Prosvirnin, D. N. (2008). O vliyanii masla marki GK na nadezhnost' elektrooborudovaniya. *Materialy plenarnogo zasedaniya soveta «Vysokovol'tnye vvody, «Obshhie problemy diagnostiki silovogo elektrooborudovaniya»*. Available at: http://www.myshared.ru/slide/58746/. Last accessed: 15.09.2016
11. Arbuzov, R. S., Zhivodernikov, S. V., Lavrov, V. Yu., Ovsyannikov, A. G., Tarasov, A. G., Tolchin V. M. et. al.; Tolchin, V. M. (Ed.) (2012). Problemnoe oborudovanie i problemy diagnostirovaniya. *Diagnostika elektricheskikh ustanovok: Materialy Sed'mogo izdaniya nauchno-prakticheskogo seminara Obshhestvennogo Soveta spetsialistov Sibiri i Vostoka po problemam diagnostiki elektricheskikh ustanovok*. Khabarovsk, 61–78.
12. Ovsyannikov, A. G., Maryushko, E. A. (2014). Problemy ekspluatatsii i diagnostirovaniya vvodov s RIP-izolyatsiey. *Energoekspert, 3,* 22–26.
13. Davidenko, I. V. (2009). Opredelenie dopustimykh znacheniy kontroliruemykh parametrov maslonapolnennogo oborudovaniya na osnove massiva nablyudaemykh dannykh. *Elektrichestvo, 6,* 10–21.
14. Davidenko, I. V. (2006). Issledovanie pokazateley, opisyvayushhikh rabochee sostoyanie maslonapolnennykh vvodov, metodami matematicheskoy statistiki. *Izvestiya vysshikh uchebnykh zavedeniy. Severo-Kavkazskiy region: Tekhnicheskie nauki*, 15, 31–33.
15. Zakharov, A. V. (2001). Obnaruzhenie defektov silovykh maslonapolnennykh transformatorov kak protsedura proverki statisticheskikh gipotez. *Novoe v rossiyskoy energetike, 2,* 19–28.
16. Shutenko, O. V. (2017). Opredelenie znacheniy granichnykh kontsentratsiy rastvorennykh v masle gazov metodom minimal'nogo riska. *Elektrichestvo, 8,* 50–60.
17. Shutenko, O. (2017). Determine the boundary value of the concentration of gases dissolved in oil of method minimum risk. *2017 IEEE First Ukraine Conference on Electrical and Computer Engineering (UKRCON)*. Kyiv, 468–472.
18. Levin, M. N. (2013). Statisticheskiy metod raspoznavaniya defektov v silovykh transformatorakh pri ikh tekhnicheskom obsluzhivanii po sostoyaniyu. *Promyshlennaya energetika, 8,* 37–41.
19. Lin, M.-J. (2015). Gaussian distribution Diagnoses in Transformer's Insulating Oil. *Joint International Mechanical, Electronic and Information Technology Conference (JIMET 2015)*. Chongqing, 824–830. doi: http://doi.org/10.2991/jimet-15.2015.154
20. Mirowski, P., LeCun, Y. (2012). Statistical Machine Learning and Dissolved Gas Analysis: A Review. *IEEE Transactions on Power Delivery, 27 (4),* 1791–1799. doi: http://doi.org/10.1109/tpwrd.2012.2197868
21. Felea, I., Secui, D., Oltean, M. (2011). The impact analyze of electric stress level in content of insulating oil gases in power transformers. *Journal of sustainable energy, 2 (4),* 7–12.
22. Shutenko, O. V., Baklai, D. N. (2014). Analiz zakoniv rozpodilu kontsentratsii haziv, rozchynenykh v masli vysokovoltnykh transformatoriv nehermetychnoho vykonannia. *Visnyk NTU «KhPI», 24 (067),* 102–117.
23. Shutenko, O. V., Baklay, D. N. (2012). Issledovanie zakonov raspredeleniya fiziko-khimicheskikh pokazateley transformatornykh masel. *Visnik NTU «KHPI», 23,* 170–186.
24. Shutenko, O. V., Baklay, D. N. (2013). Osobennosti statisticheskoy obrabotki rezul'tatov ekspluatatsionnykh ispytaniy pri issledovanii zakonov raspredeleniya rezul'tatov khromatograficheskogo analiza rastvorennykh v masle gazov. *Visnik NTU «KHPI», 60 (1033),* 136–150.
25. Gmurman, V. E. (1977). *Teoriya veroyatnostey i matematicheskaya statistika*. Moscow: Vysshaya Shkola, 479.
26. Shutenko, O. V., Baklay, D. N. (2013). Planirovanie eksperimental'nykh issledovaniy v elektroenergetike. *Metody obrabotki eksperimental'nykh dannykh*. Kharkiv: NTU «KHPI», 268.
27. Johnson, N. L., Leone, F. C. (1977). *Statistics and Experimental Design in Engineering and the Physical Sciences. Vol. 1 (Probability & Mathematical Statistics S.)*. John Wiley & Sons Inc, 618.
28. Scheffe, H. (1999). *The Analysis of Variance*. Wiley-Interscience, 477.
29. *Normy vyprobuvannia elektroobladnannia: SOU-N EE 20.302:2007*. (2007). Prykaz Minpalyvenerho 15.01.2007. No. 13. Kyiv: OEP «HRYFRE»: Ministerstvo palyva ta enerhetyky Ukrainy, 262.
30. Tret'yak, L. N. (2004). *Obrabotka rezul'tatov nablyudeniy*. Orenburg: GOU OGU, 171.

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INFLUENCE OF EXTERNAL FACTORS ON THE PROCESS OF HYDRATES DEVELOPMENT IN LABORATORY CONDITIONS

page 39–45

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The object of research is the influence of various factors on the process of synthesis of propane hydrate in laboratory conditions. It is known that a synthesized gas hydrate can contain a significant amount of ice, which reduces its gas content. The quality of the hydrate is affected by: gas pressure, water temperature, time of the experiment and the concentration of surfactants.

To study the complex effect of these factors on the quality of the hydrate obtained, an experimental setup is developed. After synthesis of the gas hydrate, its gas content is determined using a specially designed stand. In the course of the research, various measuring instruments were used: manometers, thermometers, measuring utensils, electronic scales, etc., which made it possible to obtain reliable information on the thermophysical characteristics of the synthesis and dissociation of gas hydrate.

As a result of the multivariate experiment, an array of data for analysis by mathematical statistics methods is obtained. Correlation coefficients are determined and found that the dominant factors are the gas pressure and concentration of surfactants. The water temperature should be within the operating range of 1–5 °C. The formation time of the hydrate in the bubbling regime within 0.5–5 h also does not significantly affect the quality of the obtained hydrate. For all factors, regression dependencies and graphs are constructed. It is established that for standard regression dependencies (linear, exponential, logarithmic and polynomial), the coefficients of multiple correlation are in the range 0.19–0.46. This means that the standard regression relationships do not allow to take into account all the features of the obtained results. Therefore, the selection of the optimal dependence is carried out by the method of variation of the coefficients and types of functional dependencies and an approximate formula is obtained for determining the predicted gas content of the hydrate.

The research results show that due to the complex consideration of various factors, it is possible to determine the range of optimum values of pressure, temperature and concentration of surfactants, which makes it possible to quickly produce a high-quality hydrate.

Keywords: gas hydrates, gas content of hydrate, external factors, statistical analysis.

References

1. Vedachalam, N., Srinivasalu, S., Rajendran, G., Ramadass, G. A., Atmanand, M. A. (2015). Review of unconventional hydrocarbon resources in major energy consuming countries and efforts in realizing natural gas hydrates as a future source of energy. *Journal of Natural Gas Science and Engineering, 26,* 163–175. doi: https://doi.org/10.1016/j.jngse.2015.06.008
2. Collett, T. S., Kuuskraa, V. A. (1998). Hydrates Contain Vast Store of World Gas Resources. *Oil and Gas Journal*, 90–95.
3. Makogon, Y. F., Holditch, S. A., Makogon, T. Y. (2007). Natural gas-hydrates – A potential energy source for the 21st Century. *Journal of Petroleum Science and Engineering, 56 (1-3),* 14–31. doi: https://doi.org/10.1016/j.petrol.2005.10.009
4. Trofimchuk, A. A., Cherskiy, N. V., Carev, V. P. (1979). Gidraty – noviy istochnik uglevodorodov. *Priroda, 1,* 83–88.
5. Deusner, C., Bigalke, N., Kossel, E., Haeckel, M. (2012). Methane Production from Gas Hydrate Deposits through Injection of Supercritical CO2. *Energies, 5 (7),* 2112–2140. doi: https://doi.org/10.3390/en5072112
6. Oveckiy, S., Savchuk, V. (2016). A method developed to increase technological and ecological efficiency of gas production from hydrate deposits. *Eastern-European Journal of Enterprise Technologies, 3 (10 (81)),* 41–47. doi: https://doi.org/10.15587/1729-4061.2016.72545
7. Chen, J., Wang, Y.-H., Lang, X.-M., Fan, S.-S. (2015). Energy-efficient methods for production methane from natural gas hydrates. *Journal of Energy Chemistry, 24 (5),* 552–558. doi: https://doi.org/10.1016/j.jechem.2015.08.014
8. Shiryaev, E. V. (2015). Metody bor'by s gidratoobrazovaniem i vybor ingibitora gidratoobrazovaniya pri obustroystve gazovogo mestorozhdeniya «Kamennomysskoe more». *Molodoy ucheniy, 17,* 323–326.
9. Pavlenko, A., Kutnyi, B., Holik, Y. (2017). Study of the effect of thermobaric conditions on the process of formation of propane hydrate. *Eastern-European Journal of Enterprise Technologies, 5 (5 (89)),* 43–50. doi: https://doi.org/10.15587/1729-4061.2017.111409
10. Pavlenko, A., Kutnyi, B., Holik, Y. (2017). Study of the effect of thermobaric conditions on the process of formation of propane hydrate. *Eastern-European Journal of Enterprise Technologies, 5 (5 (89)),* 43–50. doi: https://doi.org/10.15587/1729-4061.2017.108535
11. Semko, V., Leshchenko, M., Cherednikova, O. (2018). Standardization of Required Level Probability of No-Failure Operation of the Building Envelopes by the Criterion of Total Thermal Resistance. *International Journal of Engineering & Technology, 7 (3.2),* 382–387. doi: https://doi.org/10.14419/ijet.v7i3.2.14557
12. Baba Babanli, M., Shumska, L., Leshchenko, M. (2018). Heat Treatment Technology of Porous Building Materials with Predictability of Thermophysical Properties. *International Journal of Engineering & Technology, 7 (3.2),* 501–509. doi: https://doi.org/10.14419/ijet.v7i3.2.14579

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STUDY INTO ENERGY EFFICIENCY OF THE DRIVE OF ELECTRIC VEHICLES WITH AN INDEPENDENT POWER SUPPLY DEPENDING ON THE CONFIGURATION OF THE POWER SOURCE

page 45–50

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The electric vehicle with an independent power supply is the object of this research. At present, such vehicles are becoming more popular in the automobile market, pushing out their rivals with internal combustion engines, owing to their superior energy efficiency. The advantage over the internal combustion engine vehicles being obvious, the efficiency of electric vehicles is still considerably low in comparison to other electric devices. The problem that causes these limitations lies in the power supply – li-ion accumulator – which has high impedance.

In order to solve this disadvantage, the system with an ultracapacitor battery connected in parallel to the accumulator was considered using an example of the electric scooter drive with a squirrel-caged induction motor. Ultracapacitors have significantly lesser impedance than accumulators, thus they carry with themselves most of instant load during acceleration and braking when a power source supplies the highest currents.

Our study has shown that this configuration improves energy efficiency of the electric vehicles. Moreover, there is an optimal amount of ultracapacitor capacitance for achieving the best efficiency (the lowest energy consumption). This follows from the fact that an ultracapacitor battery is a rather heavy object; a significant increase in its capacitance leads to the increased vehicle weight and thus enhances energy consumption. An additional modernized system of supply was considered at which ultracapacitor's charging is accelerated during vehicle stops. Such a system has made it possible to improve the results and decrease energy consumption even larger.

Compared to previous studies, this research demonstrates the importance of correct choice of ultracapacitor capacitance and supply distribution system. The existence of the optimum point has been proven; the difference of energy consumption at this point has been demonstrated in numbers.

Keywords: electric scooter drive system, li-ion accumulator, ultracapacitor and accumulator in-parallel, urban driving cycle.

References

1. Shydlovskyi, A. K., Pavlov, V. B., Popov, A. V. (2008). Prymenenye superkondensatorov v avtonomnom akkumuliatornom elektrotransporte. *Tekhnichna elektrodynamika*. Kyiv, 79.
2. Liu, S., Peng, J., Li, L., Gong, X., Lu, H. (2016). A MPC based energy management strategy for battery-supercapacitor combined energy storage system of HEV. *35th Chinese Control Conference,* 8727–8731. doi: http://doi.org/10.1109/chicc.2016.7554751
3. Singh, A., Karandikar, P. B. (2016). Lead-acid battery for HEV using fuzzy controller and ultracapacitor. *Biennial International Conference on Power and Energy Systems: Towards Sustainable Energy (PESTSE),* 1–5. doi: http://doi.org/10.1109/pestse.2016.7516443
4. Pitorac, C. (2016). Using Li-Ion accumulators as traction batteries in the automotive industry. Cost reduction using ultra-capacitors. *International Conference on Development and Application Systems,* 212–218. doi: http://doi.org/10.1109/daas.2016.7492575
5. Butterbach, S., Vulturescu, B., Coquery, G., Forgez, C., Friedrich, G. (2010). Design of a supercapacitor-battery storage system for a waste collection vehicle. *IEEE Vehicle Power and Propulsion Conference,* 1–6. doi: http://doi.org/10.1109/vppc.2010.5729238
6. Ostroverkhov, M. Ya., Reutskyi, M. O., Trinchuk, D. Ya. (2016). Doslidzhennia robochykh rezhymiv neliniinoho elektrychnoho kola z avtonomnym dzherelom zhyvlennia v transportnykh zasobakh na prykladi pryvoda elektroskutera. Problemy enerhoresursozberezhennia v elektrotekhnichnykh systemakh. *Nauka, osvita i praktyka, 1,* 75–77.
7. Reutskyi, M. O., Trinchuk, D. Ia., Deshko, A. O. (2014). Zastosuvannia superkondensatoriv u pryvodi elektromobilia na bazi dvyhuna postiinoho strumu z nezalezhnym zbudzhenniam: proceedings. *Suchasni problemy elektroenerhotekhniky ta avtomatyky*. Kyiv.
8. 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. doi: http://doi.org/10.1109/tte.2015.2470092
9. Herrera, V. I., Gaztanga, H., Milo, A., Nieva, T., Etxeberria-Otadui, I. (2015). Optimal Operation Mode Control and Sizing of a Battery-Supercapacitor Based Tramway. *IEEE Vehicle Power and Propulsion Conference,* 1–6. doi: http://doi.org/10.1109/vppc.2015.7352988
10. Herrera, V. I., Gaztanaga, H., Milo, A., Saez-de-Ibarra, A., Etxeberria-Otadui, I., Nieva, T. (2016). Optimal Energy Management and Sizing of a Battery--Supercapacitor-Based Light Rail Vehicle With a Multiobjective Approach. *IEEE Transactions on Industry Applications, 52 (4),* 3367–3377. doi: http://doi.org/10.1109/tia.2016.2555790