IMPROVING OPERATION AND MAINTENANCE OF LOCOMOTIVES OF UKRAINIAN RAILWAYS

B. E. Bodnar, A. B. Ochkasov, D. V. Bobyr

Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan, Lazaryana St., 2, Dnipropetrovsk, Ukraine. Department "Locomotives", abochkasov@gmail.com

The results of research according to operation system improvement and locomotive technical equipment of Ukrainian railways are represented in the article. The scientific work is carried out by "Technical maintenance and diagnostics of locomotives" laboratory of Dnipropetrovsk National University of Railway Transport named after acad. V.Lazaryan. The methods and hardware and software system of train handling rational modes selection are developed for exploitation system improvement. The theoretical basis of implementation necessity of technical diagnostics equipment in locomotive unit is outlined in the article. The method for determining the limits of diagnostic parameters change is suggested. The method can be used in the preliminary stage of locomotives maintenance development system, the locomotives are equipped with on-board diagnostics systems. The examples of diagnostic systems for locomotives node points and their work results are enumerated.

Keywords: locomotive, parameter charts, train handling mode, maintenance system, diagnostic devices, failure prediction

Introduction

The challenge of reducing maintenance costs is relevant to any transportation company operating the rolling stock. In the locomotive industry the major portion of maintenance costs accounts for the costs associated with the expenditures for energy supply, as well as maintenance and repair of locomotives.

Consumption of energy resources in the complex is determined by the entire railway system. To a large extent the overall consumption of energy for traction is affected by the work of railway traffic services and technical services (of locomotive facilities and electrification, carriage facilities, track). By providing the necessary technical condition of rolling stock, track and power supply devices, these services significantly affect the ratio of the total and useful expended energy. Thus, minimization of power consumption for a predetermined amount of traffic is achieved virtually by all main railway services directly involved in the transportation process.

Main material

Employees of the department «Locomotives» of Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan conduct the research aimed at the development of rational train handling modes. The developed methods, models and algorithms allowed designing the hardware-software complex for calculation of rational modes for handling the freight train by DC electric locomotive and for readout of parameter charts. The complex provides an opportunity to accumulate and process the performed trips, to calculate quickly individual parameter charts, consumption-optimized for the train motion, taking into account the compliance with schedule, to perform traction-optimization calculations for specific operating conditions, to set the electricity consumption rate for the traction for different sections, train weights, running time, permanent and temporary speed restrictions. The software was developed allowing to save additional 4–12% of energy for traction [1, 2].

The algorithm for solving the problem of selecting the rational train handling mode in the hardware-software complex is based on the methods of discrete dynamic programming and vector optimization by the criteria for minimum energy consumption $\sum_{i=1}^{n} A_i(t_i)$ and minimum running time $\sum_{i=1}^{n} t_i$ (1).

$$\begin{bmatrix} \sum_{i=1}^{n} A_i(t_i) \\ \sum_{i=1}^{n} t_i \end{bmatrix} \to \min \tag{1}$$

The block diagram of hardware of the complex is shown in Figure 1. During the complex operation prior to the trip the recommended motion path is determined; it is displayed as shown in Figure 2.

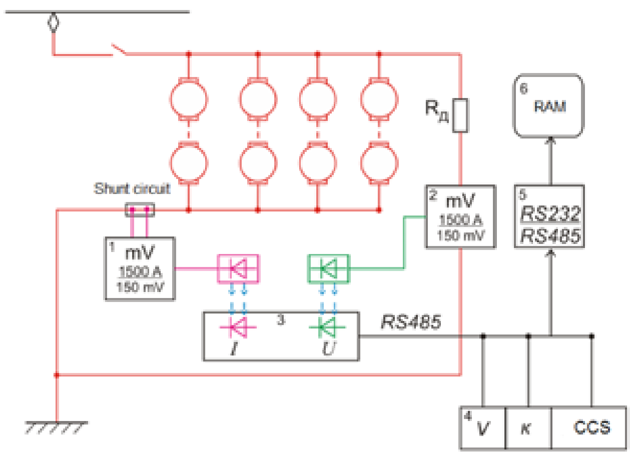

Figure 1. Block diagram of hardware of the complex. 1, 2 – LEM sensors for current and voltage of electric locomotive respectively; 3 – photodetector of current and voltage values; 4 – sensors for speed, control notches and continuous cab signalling (CCS) readings; 5 – interface converter; 6 – computing device

During the trip, along with the estimated path, the complex displays and saves in the database the record-

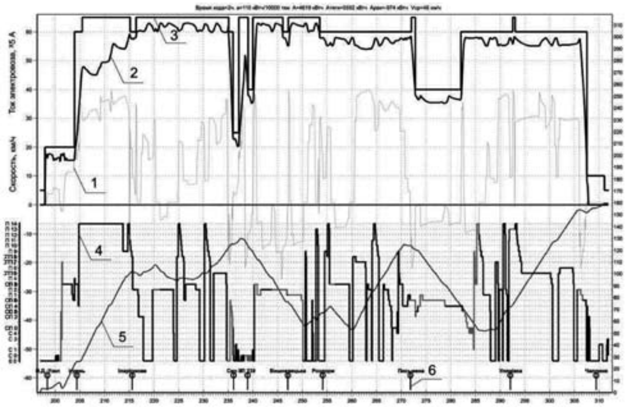

Figure 2. Recommended parameters of rational motion path. 1, 2 – electric locomotive current and recommended rational control speed respectively; 3 – speed limit; 4 – control notches; 5 – integrated track profile; 6 – axes of stations

Скорость, км/ч	Speed, km/h
Ток элетровоза	Locomotive current

ed values of speed, electric locomotive and traction motor current, traction motor switching circuit and attenuation field, actual catenary voltage, as well as provides visual and voice prompts for electric locomotive handling mode.

Currently, work is underway to establish the similar system for calculating the rational modes of freight train handling by mainline locomotives. The performed calculations of parameter charts for freight trains yielded the expected fuel saving of about 5% compared with the test running results [3].

One of the methods to reduce the operating costs of transport companies is the improvement of locomotive fleet maintenance system. Employees of the department «Locomotives» and those of the research laboratory «Technical maintenance and diagnostics of locomotives» perform studies aimed at developing methods and means of determining the actual technical condition of locomotives and their units, as well as planning the repair period and scope [4–7].

Nowadays, the repair and maintenance of locomotives of Ukrainian railways are carried out according to a fixed schedule, and the need and the type of regular repair are usually determined by the locomotive mileage. This approach does not consider the actual state of the locomotive units and the real need in repair of this type, which leads to considerable additional costs. In addition, the lack of information as to the scope and the list of repair works for the specific locomotive makes it difficult to plan the repair at a depot and significantly increases its time.

One of the solutions to this problem is to improve the methods for diagnosing and predicting changes in the technical condition of locomotive units, development of methods for determining the frequency and scope of repairs on the basis of diagnostic data and «history» of the locomotive operation.

The new traction rolling stock is equipped with onboard diagnostics systems; the main objective of such systems is to increase the reliability of locomotives and to allow transferring to the maintenance and repair of locomotives using the diagnostic results of their units.

Many failures are preceded with the gradual development of a defect, changes in physical properties, size and shape of parts. The identification of such defects without disassembling the unit before transition to a failure condition allows eliminating the defects in a timely manner with significantly less resource spent for this rather than for restoration of unit performance after its failure.

The theoretical basis for the transition to a rolling stock repair in view of its actual technical condition should become an integrated locomotive fleet management system. The existing locomotive on-board diagnostic tools enable continuous monitoring of performance of many units and assemblies of locomotives, but do not allow identifying the possible resource of trouble-free operation of each unit and assembly.

The task to predict the failure time of a technical object on the basis of the diagnosis is not new in the theory of technical diagnostics; these problems have been solved both for the railway and other modes of transport. The solution to this task is reduced to prediction of the timing of failure of the rolling stock parts.

There are various models to solve the task of predicting the failure time. The most accurate one can be considered the model that uses the current technical state data. To solve this task, you can use the following model [8]:

$$t_{fail} = t_0 + T_{res}, \quad (2)$$

where t_0 – operating time as of the date of prediction; T_{res} – predicted residual life of parts.

Calculation of T_{res} is carried out taking into account the stochastic nature of the changes in technical conditions. This approach assumes that the value T_{res} is determined taking into account the residual life distribution law Z of its parameters – the expectation M, coefficient of variation ν, and the set probability of failure-free operation $P(t)$.

$$T_{res} = f[\mathrm{Z}, \mathrm{M}, \nu, P(t)]. \quad (3)$$

These parameters are determined by analysing the information obtained as a result of diagnosing the current state of the locomotive. In order to predict the instant of failure, the accumulated statistics for each implementation (that is, each processing of diagnostic information) is displayed as the following function:

$$T_{ocm} = f(Y_T), \quad (4)$$

where $-Y_T$ value of the current technical state as of the moment of prediction t_y.

Graphical interpretation of the unit residual life prediction based on the analysis of the diagnostic parameter is shown in Figure 3.

Prediction of the instant of failure requires repeated control diagnosis. The number of inspections depends

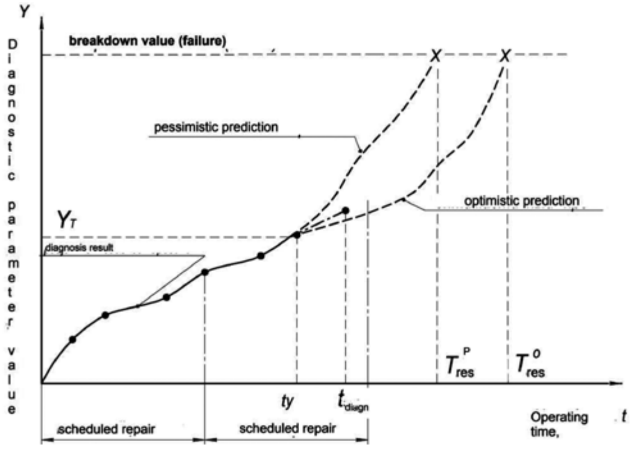

Figure 3. Unit residual life prediction based on the on-board diagnostic system data

on the technical condition of the locomotive and the diagnostic parameter change rate. In the case of on-board diagnostic system the instant of time t_y can be regarded as a period of time between the reading and processing of the on-board diagnostic system data. The result of the diagnostic data processing is the dependence of the actual changes in the diagnostic parameter on the operating time indicated by a solid line in the figure. The end result of the unit residual life determination, in any case, will be the conclusion concerning the need for repair and scope thereof.

The main task of predicting changes in the technical condition is to determine such parameters as the time of subsequent processing of diagnostic data t_{diagn} and failure (running) time. In any case, while predicting the residual life value there is a failure undetection probability due to incomplete compliance of the predicted changes in the unit technical state with the actual dynamics. From our point of view, one of the options to improve this approach may be to determine the residual life using the concepts of optimistic and pessimistic residual life. By optimistic prediction T_{res} we mean the residual life corresponding to the lowest rate of failure development, while by pessimistic prediction T_{res}, on the contrary, the highest rate of failure development. These two values will determine the acceptable limits of diagnostic parameter change. To determine the unit residual life using this approach it is necessary to analyse the dynamics of the diagnostic parameter for this unit on the other locomotives. Comparison of the rate of diagnostic parameter change in the control unit with the dynamics of diagnostic parameter change in similar units will enable to take into account the failure development features and to predict the failure occurrence more effectively.

The acceptable range of diagnostic parameter change in the simplest case can be determined using the known rule 3σ.

$$T_{res}^{p} = T_{res}^{av} - 3\sigma, \quad T_{res}^{o} = T_{res}^{av} + 3\sigma \tag{5}$$

where T_{res}^{av} – average predicted value of the residual life, σ – standard deviation of the residual life.

The proposed method can be used at the preliminary design phase of the maintenance system for locomotives equipped with on-board diagnostic systems.

The method is based on systematization and processing of diagnostic results. The disadvantage of this approach is the need to determine the distribution law of the residual life random variable and the residual life characteristics as a random variable. In cases where the random variable distribution law does not correspond to the most common distribution laws, the calculation of residual life will be difficult. In addition, the software for the calculation must have a multivariate calculation algorithm depending on the random variable distribution law.

The method which is devoid of this disadvantage is the use of artificial neural networks. Artificial neural network is a set of mathematical and algorithmic methods for solving a wide range of tasks. Characteristic features of artificial neural networks, which is a universal data processing tool, are: a flexible model for non-linear approximation of multivariate functions; time predicting possibility for the processes depending on many variables; classification by various parameters, allows partition of the input space into the areas. The neural network has the ability to learn by establishing correspondence between the control parameter change dynamics and the fact of failure onset.

The practical realization of the proposed method is carried out during the analysis of the diagnostic data of electric locomotives DE-1 and $VL11^{M/6}$. The methods for diagnostic data analysis, as well as the software tools for the calculation of reliability indicators and diagnostic data systematization were developed [4,5,9].

It is obvious that solution of the set tasks requires appropriate means of technical diagnostics, as well as methods and tools for the diagnostic data analysis. The laboratory «Technical maintenance and diagnostics of locomotives» developed a number of stationary automated stands for diagnosing locomotive units and assemblies.

There is developed variant of microprocessor system for diesel locomotive hydraulic transmission testing, which has no analogues in Ukraine [10]. Test data collection was automated in order to fix rapid processes for determination of the technical condition of a hydraulic transmission. The developed information-measuring system allows improving the hydraulic transmission testing process due to automation and improvement of the accuracy of control parameters measurement. The measurement results are the initial data for further researches to in order to determine the technical condition of the hydraulic transmission UGP750-1200 during the factory post-repair testing. The program interface is shown in Figure 4.

To test the diesel locomotives the laboratory developed an automated test stand for 1D12 type diesel. The

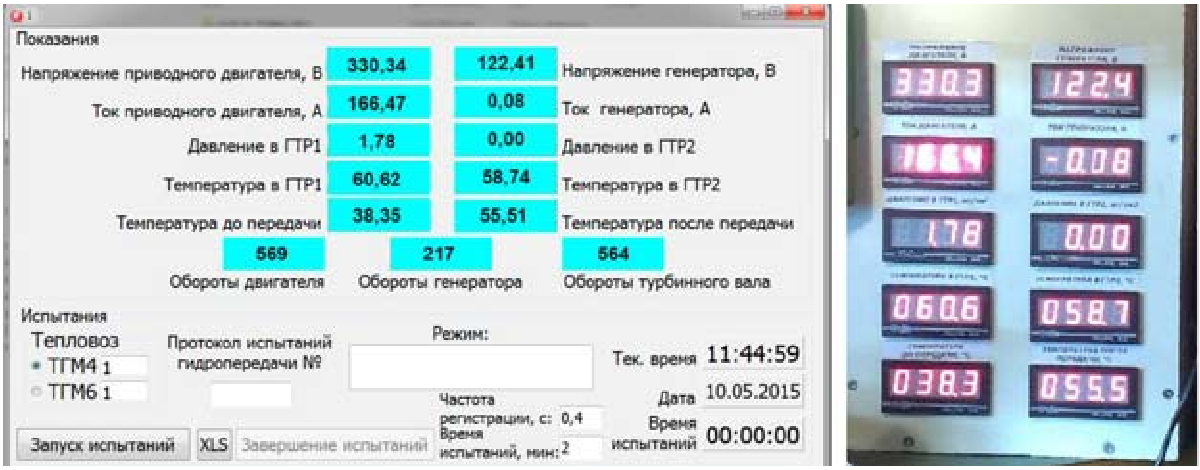

Figure 4 – Interface of hardware-software complex for diesel locomotive hydraulic transmission testing

Показания	Reading
Напряжение приводного двигателя, В	Voltage of drive motor, V
Ток приводного двигателя, А	Current of drive motor, A
Давление в ГТР1	Pressure in GTR1
Температура в ГТР1	Temperature in GTR1
Температура до передачи	Temperature before transmission
Напряжение генератора, В	Voltage of generator, V
Ток генератора, А	Current of generator, A
Давление в ГТР2	Pressure in GTR2
Температура в ГТР2	Temperature in GTR2
Температура после передачи	Temperature after transmission
Обороты двигателя	Engine rpm speed
Обороты генератора	Generator rpm speed
Обороты турбинного вала	Turbine shaft rpm speed
Испытания	Tests
Тепловоз	Locomotive
ТГМ4	TGM4
ТГМ6	TGM6
Протокол испытаний гидропередачи №	Hydraulic transmission test report №
Режим	Mode
Частота регистрации, с	Frequency of registration, sec
Время испытаний, мин	Testing time, min
Тек. время	Current time
Дата	Date
Время испытаний	Testing time
Запуск испытаний	Test start
Завершение испытаний	Test completion

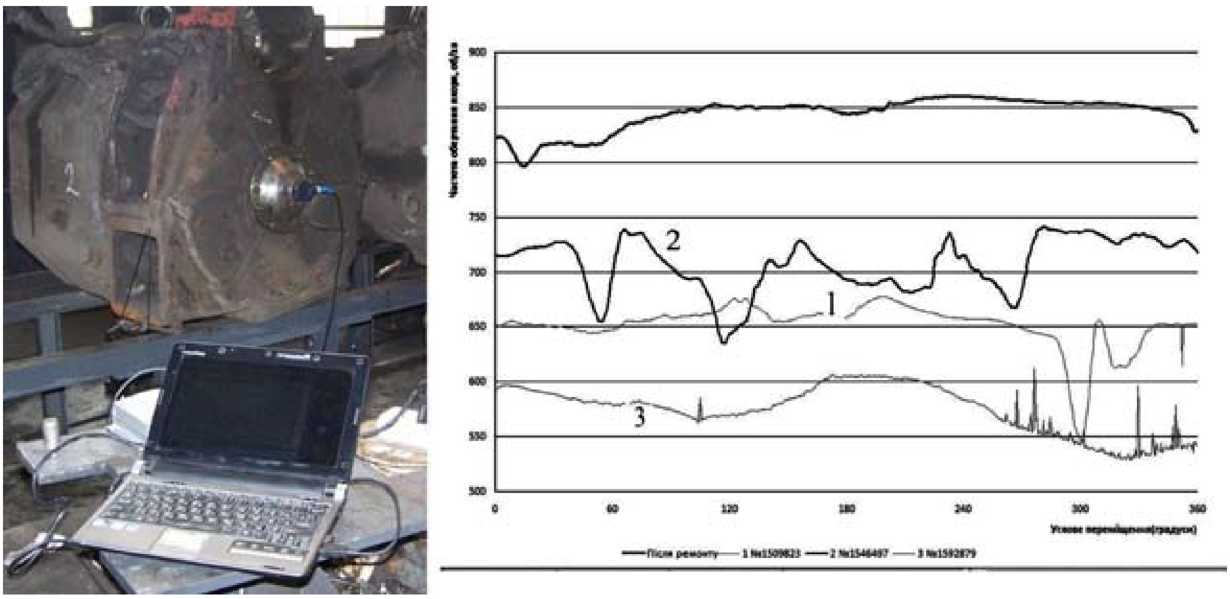

Figure 5. Execution of tests traction electric motor and results

Частота обертання якоря, об/хв	Anchor rotation speed (rpm)	Після ремонту	After repair
Углове переміщення (градуси)	Angular movement (degrees)		

stand controls more than 20 analogue parameters of a diesel generator unit. The water rheostat is used as a loading device. For the diagnosis of operating diesel locomotives we use the portable device for determination of irregularity in diesel crankshaft rotation [11] and the portable system for monitoring the working process of internal combustion engines – DEPAS 4.0 [12].

For bench diagnosis of traction electric motors we designed the non-destructive isolation diagnostic system [13] and the device for traction electric motor diagnostics by irregularity in armature shaft rotation [14]. To diagnose by irregularity in armature shaft rotation it is proposed to use a high-precision rotary encoder. Diagnosis is carried out when the motor is idling. This diagnosis system is available and does not require significant investments in its implementation. The possibility of using the proposed method of traction motor diagnosing is confirmed by experimental studies aimed to determine the irregularity in armature shaft rotation and connection of the latter with faults of TEM (traction electric motor) units. The experimental results are shown in Figures 5 and the overall view of the equipment is shown in Figure 5. The diagrams 1-3 (see Figure 5) correspond to the motors with faults, the upper diagram corresponds to the motor after the repair.

Conclusions

The analysis of the available devices for locomotive unit diagnosing leads to the conclusion that their current implementation allows:

– improving the traffic safety (preventing form accidents while driving, controlling the actions of the locomotive crew);
– reducing the time for troubleshooting in electrical circuits (controlling the response of electrical apparatus);
– identifying (and more often – confirming) the fact of failure onset in controlled units.

In fact, the diagnosis systems have monitoring function over the changes in the technical state of locomotives units.

From the perspective of technical diagnosis the main tasks of any diagnostic system are:

– performance measurement of diagnosed object (fault-free/faulty);
– operation control (control in order to avoid any failure that can violate the performance);
– troubleshooting (fault identification and ways to fix it);
– predicting changes in the technical state of the diagnosed object in the future;
– definition of the previous state of the diagnosed object.

The existing diagnosing methods to some extent perform the first three tasks, but their solution does not clearly determine the repair scope and scheduling, which is necessary for transition to the repair of rolling stock in view of its actual technical state. Further improvement of the locomotive maintenance system is based on the multiple diagnoses of locomotives and their units, accumulation of diagnostic knowledge data base and its analysis according to the developed techniques. The solution of these tasks will allow carrying out the transition to the locomotive maintenance system based on the actual technical state of locomotives.

References

1. Bobyr Dmitry Valeriyevich *Usovershenstvovanie rezhimov vedeniya gruzovogo poyezda s elektritcheskoy tyagoy* [Improved modes of freight train handling with electric traction] [Text]: PhD Tech. Sc. dissertation: 05.22.07; Dnipropetrovsk National University of Railway Transport named after Academician V.Lazaryan. – D., 2007. – 190 p. – Bibliogr.: pp. 146-156
2. Bodnar B. E., Bobyr D.V., Lyashuk V.M., Ivanov A.P. *Programny kompleks po raschetu energooptimalnyh rezhimov vedeniya poezrdov // Problemy i perspektivy razvitiya zheleznodorozhnogo transporta* [Software for analyzing energy-optimized train handling modes // Problems and prospects of railway transport development]: Proceedings of the LXVI International research and practice conference – Dnepropetrovsk: DNURT, 2006. – P. 48.
3. Bondar B.E. et al. *Ispolzovanie informatsiyi bortovyh sistem diagnostirovaniya pri opredeleniyi tehnicheskogo sostoyaniya uzlov lokomotiva* [Using the information board diagnostic systems in determining the technical condition of the locomotive units] *Science and Transport Progress. Bulletin of Dnipropetrovsk National University of Railway Transport* (2008).
4. Bodnar B.E., Ochkasov A.B., *Povysheniye ekspluatatsionnoy nadezhnosti podvizhnogo sostava: razvitiye system diagnostirovaniya* [Increase of rolling stock operational reliability: the development of diagnostic systems] // *Locomotive inform* №1-2, p.56-58, Kharkiv, 2011
5. Bodnar B.E., Ochkasov A.B., Liubka V.S. *Usovershenstvovaniye sistemy tehnicheskogo soderzhaniya lokomotivov* [Improvement of the technical content of locomotive system] // *Locomotives. XXI Century. Proceedings of the II International Scientific Conference dedicated to the 90th anniversary of the start of the domestic locomotive construction, 140th anniversary of Doctor of Technical Sciences, Professor Gakkel J.M., 205th anniversary of the Institute of Railway Engineers Corpus.* St. Petersburg, 2014. p.130-134
6. Bodnar B.E., Ochkasov A.B., Shvets O.M. *Primeneniye neyronnyh setey dlya opredeleniya tehnicheskogo sostoyaniya lokomotivov* [Application of neural networks to determine the technical state of locomotives] // *Locomotive Inform* №9-10, p.4-6, Kharkiv, 2009
7. Bodnar, B. Y., Ochkasov, O. B., Detsyura, O. Y., Chernyayev, D. V. (2012). Methods of nonseparable diagnostics of diesel engines in operation of rolling stock. *Science and Transport Progress. Bulletin of Dnipropetrovsk National University of Railway Transport*, (41), 56-60.
8. Bodnar B. E., Ochkasov A.B., Chernyaev D.V. Shevchenko Y.I. Diagnostirovaniye tyagovyh elektrodbigateley po neravno-

mernosti vrashcheniya yakorya [Diagnosis of traction electric motor at irregularity in speed of anchor rotation] // Science and Progress transport. Bulletin of Dnipropetrovsk National University of Railway Transport. 2013. №3 (45).

9. Chentsov M.O., *Zagalniy vyd modeli prognozuvannya terminu vidmovi detaley mashyn na stadiyi ekspluatatsiyi* [General view of the model for prediction of machine parts failure during operation] / Chentsov M.O., Ruchko V.M. // *Int. Coll. of scientific papers: Progressive Manufacturing Engineering.*-1998.- № 5.- pp. 121-124.
10. Depas Laboratory. Access via Internet. < http://depas.od.ua/
11. Kapitsa M.I. et al. *Viznachennya energozaoschadzhuyuchih rezhimiv rozgonu poyizdiv.* [Determination of the energy saving modes of train acceleration] – 2015.
12. Kapitsa M.I. *Postroenie integralnoy funktsii raspredeleniya otkazov po funktsii soprotivlyaemosti izolyatsii obmotok vozbuzhdeniya* [Building integrated distribution function of failures by field class insulation resistance function TEM] / Kapitsa M..I // Visnik of Shidnoukr. Nat. University n.a. V. Dal. – Luhansk, 2003. – № 9 (67). – P. 34-38.
13. Ochkasov O.B. *Udoskonalennya bortovoi systemy diagnostuvannya elektrovoza* 05.22.07. – *Rukhomiy sklad zaliznyts' ta tyaga poyizdiv* [Improving electric locomotive onboard diagnostic system 05.22. 07-rolling stock and train traction]. 2005
14. Zhukovytskyy I. V., Kliushnyk I. A., Ochkasov O. B ., Korenyuk R. O. Information-measuring Test System of Diesel Locomotive Hydraulic Transmissions // *Science and Transport Progress.* – 2015. – № 5 (59). – C. 53–65.

УСОВЕРШЕНСТВОВАНИЕ ЭКСПЛУАТАЦИИ И ТЕХНИЧЕСКОГО СОДЕРЖАНИЯ ЛОКОМОТИВОВ УКРАИНСКИХ ЖЕЛЕЗНЫХ ДОРОГ

Б. Е. Боднар, А. Б. Очкасов, Д. В. Бобыр

Днепропетровский национальный университет железнодорожного транспорта имени академика В. Лазаряна

Аннотация. В статье представлены результаты работ по усовершенствованию системы эксплуатации и технического содержания локомотивов украинских железных дорог. Научные работы выполнены лабораторией «Техническое содержание и диагностирование локомотивов» Днепропетровского национального университета железнодорожного транспорта имени ак. В.Лазаряна. Для усовершенствования системы эксплуатации локомотивов разработаны методы и программно-аппаратный комплекс для выбора рациональных режимов вождения поездов. Комплекс позволяет накапливать и обрабатывать выполненные поездки, оперативно рассчитывать индивидуальные режимные карты, оптимизированные по минимуму расходов на перемещение поезда, с учетом выполнения графика движения, выполнять тягово-оптимизационные расчеты для конкретных условий эксплуатации, нормировать расходы электроэнергии на тягу для разных участков, масс поездов, времени хода, постоянных и временных ограничений скорости. Разработано программное обеспечение, которое позволяет дополнительно экономить 4–12% электроэнергии на тягу. В статье изложено теоретическое обоснование необходимости внедрения технических средств диагностирования в локомотивном хозяйстве. Предложен метод определения допустимых пределов изменения диагностического параметра который может быть использован на предварительном этапе разработки системы содержания локомотивов оборудованных бортовыми системами диагностирования. Приведены примеры диагностических комплексов для узлов локомотивов и результаты их работы. Представлены информационно-измерительная система для испытаний гидравлических передач УГП 750/1200, автоматизированный испытательный стенд дизелей типа 1Д12 и устройство диагностирования тяговых электродвигателей по неравномерности вращения вала якоря.