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Application Potential of Express Diagnostics Package (Exsys, IMDC-2) for Diesel Locomotive Engines

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ABSTRACT

The paper reveals aspects of application of the hardware and software package developed by the author for express diagnostics of internal combustion engines.

The objective of the research was to develop algorithms, hardware and software framework for system diagnostics of diesel engines as a comprehensive methodology aimed at localising faults in the best way.

Research methods included mathematical modelling for building the algorithm of the expert system; methods of observation and experiment used in the design work and improvement of the developed hardware and software package.

The use of on-line diagnostics methods is the main factor for the transition to a more efficient condition-based maintenance system, which makes it possible to prevent sudden failures due to diagnostics made during the simplest types of maintenance, as well as to avoid dismantling of nodes with a resource sufficient for further operation. On-line diagnostic methods are divided into organoleptic and indicator ones and belong to the first two levels of system diagnostics as a practical methodology and scientific discipline.

Organoleptic data are based on human perception organs and can be formalised using the Exsys expert system developed by the author based on open databases on correlation of faults with their symptoms, which makes it possible to localise the fault in an interactive mode based on the totality of observed external features, such as smoky exhaust of a certain colour, unstable idling, etc.

The second development, which is the IMDC-2 package, refers to indicator methods, representing a subclass of dynamic diagnostics. The package consists of an analog-to-digital converter with a shaft speed sensor mounted on the engine and a computer program that interprets the received data. IMDC-2 allows determining the engine power, building acceleration / coasting retardation curves, and obtaining several other characteristics important for diagnostics, for example, the dependence of the angular acceleration of free acceleration of the engine on the frequency of rotation of its shaft. Both developments can be fully applied after minor modification to diesel locomotive engines, which will increase the accuracy of fault detection and reduce the time for their localisation.

Keywords: *transport, diesel locomotive engine, internal combustion engine, technical diagnostics, expert system, indicator methods.*

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INTRODUCTION

The growth of availability factor is among key factors in increasing the performance of enterprises of transport and other sectors in the current economic environment. In other words, it means the reduction of downtime for technical maintenance (TM) and technical maintenance and repair (TMR) with a corresponding increase in useful work time. These goals can be achieved by implementing condition-based maintenance elements. Within the framework of this system, the frequency of TMR of various components of the object (locomotive, tractor, car…) is determined by diagnosing the resource when performing the lowest possible types of TMR.

A flexible system of diagnostic methods, tools and technologies is called system diagnostics. Its scientific substantiation in the country was obtained back in the early 1970s by V. I. Belskikh, V. M. Mikhlin, V. A. Chechet, researchers at the GOSNITI Institute. During the experiment reflected in [1], it was determined that adjustment of repair and maintenance actions based on the results of pre-repair diagnostics of tractors makes it possible to reduce the volume of overhauls by almost 30 %, including through the execution of part of major repairs during current repairs. Also, the adoption of elements of condition-based maintenance makes it possible to reduce the number of failures during operation, and, consequently, the number of unscheduled repairs (for the agricultural industry in which the described experiment was carried out, this factor is especially important, since the operation of high-power engines is time focused, and the failure of even a single vehicle can seriously affect the performance).

The structure of the repair cycle in transport sector is similar to that used in the agro-industrial complex, so the adoption of system diagnostics can be carried out using similar algorithms. Also, overall checkout allowing improvement of road safety is used at the authorised car inspection points, the equipment of which is discussed in detail in the monograph [2].

Currently, the intensive development of microprocessor technology, including analog-to-digital converters (ADC), makes it possible to significantly expand the possibilities of diagnosing both internal combustion engines and elements of the traction engines of locomotives and other mobile vehicles. The possibility to connect ADC to a computer with further displaying of output readings for current indication and further processing. In addition, such a diagnostic format allows reducing the number of mechanical elements in diagnostic equipment, limiting it to installing sensors only (pressure, vibration sensors, etc.). All this, coupled with modern methods of data processing, improves the accuracy, and reduces the complexity of diagnosing.

Research Objective

The general objective of diagnostics is to localise faults that caused one or another failure, or to determine the residual resource of the object. In the framework of this work, the *objective* of research and design is development and modernisation of methods and tools for diagnosing internal combustion engines, focused on the methodology of system diagnostics.

Research Methods

The development of the described hardware-software is closely related to the *methods* of observation and experiment. Mathematical modelling was used to develop the algorithmic core of the expert system. A literature review is also an important method allowing to specify the requirements for the results of the work, as well as to avoid possible errors.

Review of Modern Methods of Express Diagnostics of ICE

Within the framework of system diagnostics, the work [3] by the staff of the department of Machine and Tractor Fleet Operation and High Technologies in Crop Production of Russian State Agrarian University – Moscow Timiryazev Agricultural Academy (RSAU–MTAA), including the author, outlined that basics and assumed division into three levels of diagnostic methods and tools: organoleptic, indicator and in-depth ones.

The first level suggests formalising the *organoleptic signs* of engine operation and using the data obtained to make a diagnosis. Organoleptic signs are those characteristics of the operation of an object that can be obtained without special tools, only with the help of the senses. Such signs include exhaust colour, unstable engine operation, overheating, etc.

Precisely, the main task here is to formalise the signs and to comprehensively use them. Such intellectual tasks can only be solved by experts in the field of diagnostics owing extensive expertise in operation and maintenance of internal combustion engines. Specialists of this level are a very valuable and rare human resource. The so-called expert systems, which are in a certain sense artificial intelligence that simulates the thinking of expert diagnosticians, are capable of partially taking over their duties. The input data for expert systems can consist of both organoleptic signs and sensor readings.

In domestic practices, expert systems are developed mainly for analysing data obtaining from sensors installed on an object for diagnostics. There is an opinion that the onboard electronic systems of ground vehicles have a wide range of diagnostic capabilities, however, as established by the author in [4], this is fully true only for vehicles such as modern diesel locomotives. In particular, the authors of [5] developed an expert system that uses the readings of on-board sensors of a diesel locomotive to monitor operation and make diagnoses. With regard specifically to diesel engines, domestic scientists have developed several expert systems similar to those described in [6] however, their use is limited by the fact that these systems are only models that require external software for operation. Thus, it is of interest to implement a self-sufficient expert system that can work without being tied to other software.

The second level of system diagnostics includes *indicator method*s that allow getting readings online using sensors, the installation of which is not laborious. A characteristic feature of such methods is that they are not too high accurate, which is compensated by the efficiency and complex use of indicator diagnostics. Data from a single method are unable to give a full representation of the state of the object, but additional studies can significantly increase the accuracy of the diagnosis.

As a rule, indicator methods are subdivided, according to the physical processes underlying them, into, for example:

• Pneumatic methods that use parameters of state (pressure, including its dynamics, flow rate) of the gaseous medium at various points of the engine. Similar methods are described, for example, in [7].

• Hydraulic methods, during which the indicators associated with the operating fluids of the engine (oil, fuel, coolant) are observed [8].

• Acoustic and vibrational methods based on the analysis of oscillograms of mechanical vibrations [9].

• Electrical methods focused on the processes occurring in the electrical equipment of the engine: for example, analysis of the starter current oscillogram.

• Dynamic methods allowing based on engine dynamics (acceleration, retardation, idle behaviour) to detect a decrease in its performance and to set key points for further troubleshooting.

In-depth methods, which constitute *the third level* of system diagnostics, have the highest accuracy of diagnosis, but require partial disassembly of the engine to access the diagnosed nodes. Regarding diesel engines, in-depth methods are studied, for example, at the department of Electric Trains and Locomotives of Russian University of Transport by V. N. Balabin, V. Z. Kakotkin, I. I. Lobanov, and are described in the work [10].

Foreign experts have formed a slightly different approach to the diagnosis of internal combustion engines since diagnostics practices of some countries comprise also monitoring of the environmental performance of the engine and even direct inspection of the combustion processes in the cylinder. The monograph [11] of the authors from India and the USA illustrates this approach addressing many issues related to diesel engines. In Eastern European countries, the concept of diagnostics is closer to domestic practices, for example, the article [12] of the Slovakian authors considers in similar way the issues of diagnosing the engine of a 812 series rail bus.

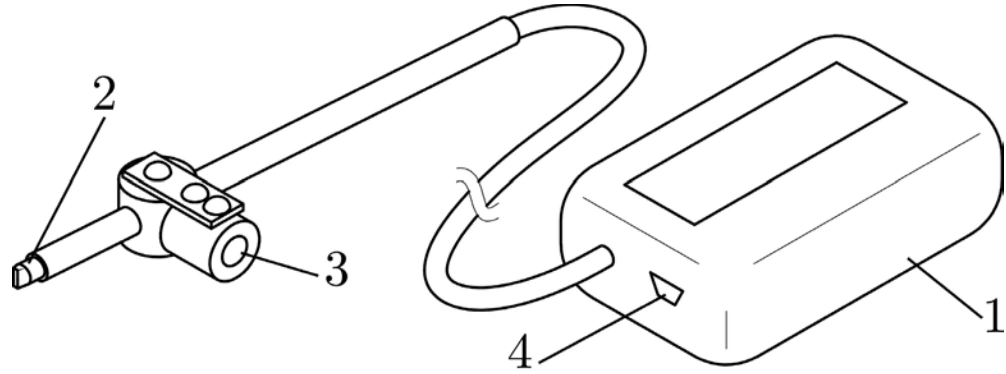
RESULTS

Package for Express Diagnostics of ICE and its Modernisation

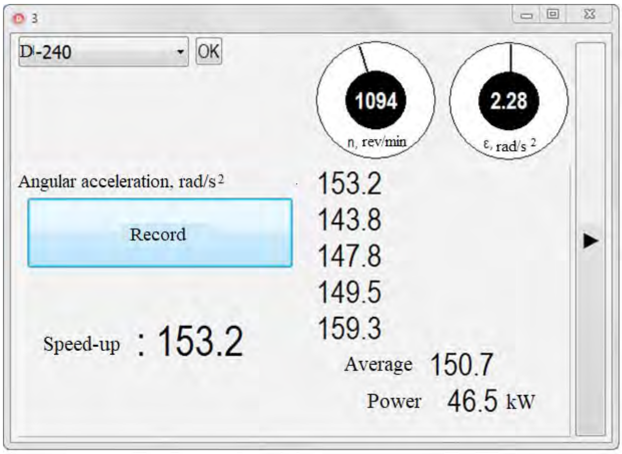
The author has developed and is upgrading a hardware and software package for express diagnostics, consisting of the Exsys expert system (registration certificate [13]), and IMDC-2 package for dynamic diagnostics.

The Exsys expert system is based on fuzzy logic and uses the conditional probabilities P_{ij} of the presence of the sign S_j in the event of a fault D_i. The so-called force coefficient S_i is also considered, which characterises the strength of manifestation of the observed feature or the operator's confidence in its presence. After the user selects the signs, the first pass of the so-called inverse algorithm based on double negation is implemented:

$$P_i = 1 - \prod_j \left(1 - s_j \cdot P_{ij}\right). \quad (1)$$



Pic. 1. IMDC-2 device [compiled by the author].



Pic. 2. IMDC-2 interpreter program interface. Based on translated screenshot during the operation of D-240 engine [made by the author].

The algorithm determines the probabilities P_i of the presence of faults («a posteriori»), presented by the program in the form of a list in descending order. If for any of the faults the established accuracy of diagnosis (80 %) was not obtained, the system in the dialogue mode with the user highlights the so-called prevailing faults, in which the a posteriori probability is higher than 0,5 of the maximum probability. For each of those faults, the prevailing signs are determined by a similar mechanism. The next step of the algorithm is to calculate the maximum relative deviation Δ_{rel}^{max} using formula (1) to determine the most characteristic, «contrasting» features that allow the most efficient separation of possible faults:

$$\Delta_{\max}^{rel} = P_{\max}\left(\frac{P_{\max} \bullet N}{\sum_{j=1}^{N} P_{ij}} - 1\right), \qquad (2)$$

where P_{max} is the maximum conditional probability for the current feature;

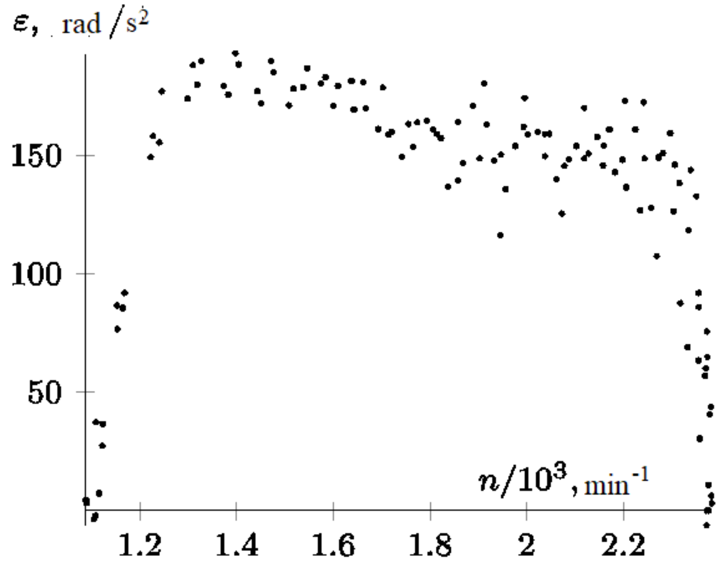
N – the number of considered prevailing faults.

After reaching the required accuracy of the diagnosis or when the possibilities of the dialog mode are exhausted, the program displays the final list of possible malfunctions. Once a specific fault is selected, a brief help on it is displayed.

Within the Exsys system, a theoretical basis for recognition of indicator signs has also been created followed by further transformation into conditional probabilities.

Exsys version 1.0 is implemented in the Delphi programming language.

The IMDC-2 hardware-software package is designed to determine the dynamic performance of the engine in transient conditions. The principle of operation of the package is based on measuring the crankshaft speed and determining its dynamics. The name of the package is a direct reference to the IMD-C device, developed in the 1980s, but now obsolete. Both devices can determine engine power without the use of stationary equipment, such as rheostat testing bench or engine dynamometer system, the



Pic. 3. Dependence of the angular acceleration of the of the crankshaft speed-up on the frequency of its rotation (D-240 diesel engine). Experimental data, rendered using PGFPlots [compiled by the author].

operation of which for cars is considered in the article [14].

IMDC-2 is shown in Pic. 1 and consists of a sensor 2, its mount 3 and ADC 1 connected to the computer. The sensor detects the passage of a magnet glued into the marker disk mounted on the engine crankshaft pulley. An interpreter program is installed on the computer, which in accordance with Pic. 2, displays the current motor shaft speed and its angular acceleration. Diagnostics is performed by sharply pressing the fuel supply control pedal. While the engine speed increases to the maximum, the program displays the obtained angular acceleration at the point of nominal speed. According to the results of five consecutive measurements, the average value of the angular acceleration is identified, then based on this value and the digitised nomograms[1], the engine power is determined. After the «Record» button is pressed, the following indicators are recorded in the file: time of one revolution in microseconds, rotational speed, and angular acceleration of the motor shaft. Also of great interest are the obtained dependences of angular acceleration on engine speed, the shape of which, presumably, can change depending on engine malfunctions, which is subject to further research on a wide range of engines' models. A characteristic of that kind is shown in Pic. 3. When considered using the time axes, the acceleration characteristics (Pic. 4) can be useful for diagnosing the diesel controller, which is partially considered in [15].

The IMDC-2 package is made using a low-budget hardware basis, which allows it to be widely used in locomotive depots (sheds), at technical inspection points and even in the field conditions. The installation of the sensor and the marker disk is carried out quickly, the only condition is to stop the diesel engine.

The weak points of the first generation of the package include the following factors:

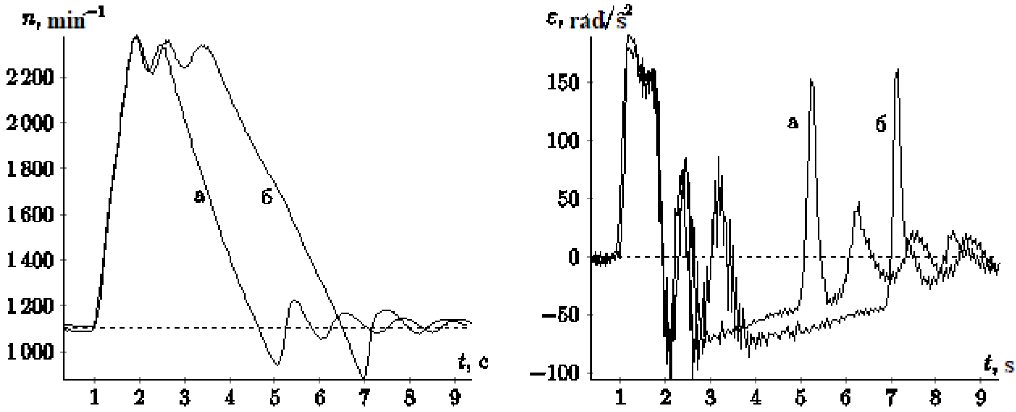
• The use in the expert system of databases based on Microsoft Excel tables requires the installation of additional software not only for editing bases, but also for direct interaction of the expert system with them.

• Complexity of using formula data: the Delphi language, despite its convenience, is outdated and does not have a mechanism for recognising and transferring text formulas into program code.

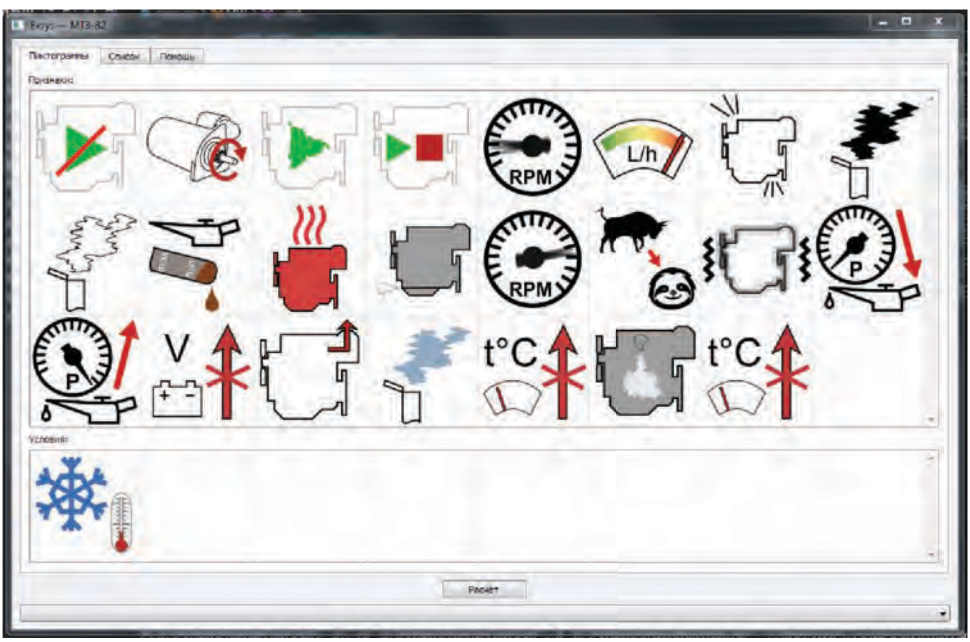
• Low data transfer rate from ADC: data is transmitted in text form, which significantly reduces the sampling rate of the received data.

• Reduced accuracy compared to the IMD-C instrument, which, however, is compensated by an increase in measurement repetitions. Besides, the inaccuracy of tuning is completely excluded in IMDC-2.

[1] Chechet, V. A., Egorov, V. V., Maistrenko, N. A., Butuzov, A. E., Levshin, A. G. Technical diagnostics of tractors: Study guide [*Tekhnicheskaya diagnostika traktorov: uchebnoe posobie*]. Moscow, Russian State Agrarian University – Moscow Timiryazev Agricultural Academy, 2018. [Electronic resource]: http://elib.timacad.ru/dl/full/s05032022tdtEgorov.pdf/en/info. Last accessed 27.08.2021.



Pic. 4. Oscillograms of engine speed and angular acceleration (D-240 diesel engine). Experimental data, rendered using PGFPlots [compiled by the author].



Pic. 5. Graphical interface of the Exsys v2.0 expert system. Screenshot during diagnostics of D-240 diesel engine [compiled by the author].

In this regard, the author is currently completely updating the software base of the package based on the Python language, which is widely used to solve problems of scientific research and artificial intelligence. The results obtained include the following:

• Due to the transition to byte-by-byte data transmission, the sampling rate has been increased to 7 kHz, which makes it possible to integrate a low-budget oscilloscope with that hardware basis to record cyclic processes occurring in the engine.

• Expert system database files do not depend on external software and store all the necessary data with the possibility of including formulas, images, etc.

• Due to the use of the PyQt graphical shell, the convenience of working with the expert system has been significantly improved, including the transition to the use of symbolic graphics (Pic. 5).

Adaptation of the package for diesel locomotive engines does not seem to be a difficult task, since the processes occurring within the engines are the same for all diesel engines. Moreover, since the frequency of rotation of the crankshaft of diesel locomotive engines is lower, it seems possible to place several magnets on the marker disk (the only condition is high accuracy in the placement of magnets, achievable, for example, using laser cutting machines). By itself, the magnetic principle of operation of the device is not the single one at all and can be replaced by placing an optical sensor that records the slots on the marker disk.

Currently, work is underway to modify the IMDC-2 device to be used in the research using the D49 diesel engine at the department of Electric Trains and Locomotives of Russian University of Transport.

CONCLUSIONS

The described hardware and software package for diagnosing internal combustion engines has a high potential for diagnosing diesel engines of all sizes, including diesel engines installed on locomotives and ships. After making some changes to the design, it is possible to increase its accuracy when using for diagnosing diesel locomotives engines. The main advantage of the package is its low-budget design and installation efficiency, which makes it possible to diagnose a diesel engine in the field conditions with further localisation of possible malfunctions and failures.

REFERENCES

1. Belskikh, V. I. Indicators of the technical condition of tractors and means for their identification [*Pokazateli tekhnicheskogo sostoyaniya traktorov i sredstva dlya ikh opredeleniya*]. *Tekhnika v selskom khozyaistve*, 1971, Iss. 9, p. 70.
2. Kalyavin, V. P., Davydov, N. A. Reliability and diagnostics of motor vehicles: Monograph [*Nadezhnost i diagnostika avtomotransportnykh sredstv*]. St. Petersburg, Elmor publ., 2014, 466 p.
3. Chechet, V. A., Levshin, A. G., Skorokhodov, A. N., Egorov, V. V. Main provisions of system diagnostics of vehicles [*Osnovnie polozheniya sistemnoi diagnostiki mashin*]. *Vestnik FGOU VPO «MGAU im. V. P. Goryachkina»*, 2018, Iss. 6 (88), pp. 51–55. [Electronic resource]: http://elib.timacad.ru/dl/full/vmgau-09-2018-06.pdf/download/vmgau-09-2018-06.pdf. Last accessed 27.08.2021.
4. Egorov, V. V. Scope of on-board diagnostics of self-propelled technical vehicles [*Oblast primeneniya bortovoi diagnostiki samokhodnykh tekhnicheskikh sredstv*]. *International scientific conference of young scientists and specialists dedicated to the 100th anniversary of I. S. Shatilov – RSAU–MTAA*, 2017, pp. 295–297. [Electronic resource]: https://elibrary.ru/item.asp?id=36668361. Last accessed 27.08.2021.
5. Kim, S. I., Kharitonov, V. I., Dolganova, E. V., Kim, S. V. Built-in expert system for rapid test diagnosis of locomotives, that are equipped with MSU-T system (P, E). *BRNI*, 2014, Iss. 4 (13), pp. 46–50. [Electronic resource]: http://brni.info/download/%D0%B2%D1%8B%D0%BF%D1%83%D1%81%D0%BA-16-17.pdf. Last accessed 27.08.2021.
6. Polkovnikova, N. A., Kureichik, V. M. Development of an expert system model based on fuzzy logic. *Izvestiya YuFU. Engineering sciences*, 2014, Iss. 1 (150), pp. 83–92. [Electronic resource]: https://elibrary.ru/item.asp?id=21111405. Last accessed 27.08.2021.
7. Kolunin, A. V., Shudykin, A. S., Belokopytov, S. V. Determining the status of the cylinder group of engines of military vehicles for the flow of crankcase gases. *Izvestiya TulGU. Technical sciences,* 2018, Iss. 11, pp. 583–588. [Electronic resource]: https://elibrary.ru/item.asp?id=36573798. Last accessed 27.08.2021.
8. Shevtsov, Yu. D., Dudnik, L. N., Chernukha, Yu. V., Fadeev, E. D., Nikiforov, A. M. Algorithm for diagnosing engine health by parameters of frequency characteristics of oil filter. *Nauchno-tekhnicheskie vedomosti SPbGPU. Informatika. Telekommunikatsii. Upravlenie*, 2018, Iss. 4, pp. 63–70. [Electronic resource]: https://infocom.spbstu.ru/userfiles/files/articles/2018/4/63-70.pdf. Last accessed 27.08.2021.
9. Gritsenko, A. V. Diagnostics of the gas distribution mechanism by the vibroacoustic method [*Diagnostirovanie gazoraspredelitelnogo mekhanizma vibroakusticheskim metodom*]. *Bulletin of the South Ural State University. Series: Engineering,* 2017, Iss. 3, pp. 48–57. DOI: 10.14529/engin170306.
10. Balabin, V. N., Kakotkin, V. Z., Lobanov, I. I. Results of use of the complex monitoring system and diagnostics of locomotive diesels. *Sovremennie naukoemkie tekhnologii*, 2014, Iss. 9, pp. 11–16. [Electronic resource]: https://elibrary.ru/item.asp?id=22025115. Last accessed 27.08.2021.
11. Agarwal, A. K., Gupta, J. G., Sharma, N., Singh, A. P. Advanced Engine Diagnostics. Singapore, Springer, 2019, pp. 3–6. DOI: 10.1007/978-981-13-3275-3_1.
12. Ondriga, J., Zvolenský, P., Hrček, S. Application of technical diagnostics in the maintenance of the internal combustion engine of diesel multiple units 812 series. *Transportation Research Procedia,* 2021, Vol. 55, pp. 637–644. DOI: https://doi.org/10.1016/j.trpro.2021.07.030.
13. Expert system of technical diagnostics based on open databases (Exsys v1.0). – Certificate of registration of the computer program 2019612928. V. A. Chechet; V. V. Egorov. (appl. date 02.2019). [Electronic resource]: https://elibrary.ru/item.asp?id=39311673. Last accessed 27.08.2021.
14. Savenkov, N. V., Ponyakin, V. V., Chekulaev, S. A., Butenko, V. V. Modern equipment for determining tractor-speed properties of the vehicle: characteristics' analysis in laboratory conditions. *Vestnik SibADI*, 2019, Iss. 3 (67), pp. 276–289. [Electronic resource]: https://elibrary.ru/item.asp?id=38538411. Last accessed 27.08.2021.
15. Dzhalolov, U. H., Yunusov, N. I., Tursunbadalov, U. A., Ziyoev, Sh. Sh., Khasanov, Dzh. R. Parameters' Identification of Acceleration Characteristic of Internal Combustion Engine. *Vestnik PNIPU. Elektrotekhnika, informatsionnie tekhnologii, sistemy upravleniya*, 2020, Iss. 35, pp. 43–56. DOI: 10.15593/2224-9397/2020.3.03. ●

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