IMPROVING OPERATION AND MAINTENANCE OF LOCOMOTIVES OF UKRAINIAN RAILWAYS

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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).

\[
\begin{align*}
\text{min} & \quad \sum_{i=1}^{n} A_i (t_i) \\
\text{subject to} & \quad \sum_{i=1}^{n} t_i 
\end{align*}
\] (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](image-url)
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 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]:

\[
T_{\text{res}} = t_0 + T_{\text{r}}.
\]  

(2)

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

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

\[
T_{\text{res}} = f[Z, M, \nu, P(t)].
\]  

(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:

\[
T_{\text{cum}} = f(Y_j),
\]  

(4)

where \( -Y_j \), value of the current technical state as of the moment of prediction \( t_j \).

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
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 $t$ 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 $t_{\text{diag}}$ 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 $T_{\text{res}}^o$ we mean the residual life corresponding to the lowest rate of failure development, while by pessimistic prediction $T_{\text{res}}^p$, 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 $3\sigma$.

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

where $T_{\text{res}}^{av}$ – average predicted value of the residual life, $\sigma$ – 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 VL11M/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

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

### Figure 5. Execution of tests traction electric motor and results

<table>
<thead>
<tr>
<th>Частота обертання якоря, об/чв</th>
<th>Anchor rotation speed (rpm)</th>
<th>Після ремонту</th>
<th>After repair</th>
</tr>
</thead>
<tbody>
<tr>
<td>Углове переміщення (градуси)</td>
<td>Angular movement (degrees)</td>
<td></td>
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</table>
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.

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УСОВЕРШЕНСТВОВАНИЕ ЭКСПЛУАТАЦИИ И ТЕХНИЧЕСКОГО СОДЕРЖАНИЯ ЛОКОМОТИВОВ УКРАИНСКИХ ЖЕЛЕЗНЫХ ДОРОГ

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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-оптимационные 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.