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RESEARCH OF THE RATIONAL OPERATIONAL LOAD OF DIESEL LOCOMOTIVES

OCENA NIEZAWODNOŚCI EKSPLOATACYJNEJ URZĄDZEŃ ENERGETYCZNYCH SPALINOWYCH LOKOMOTYW TOWAROWYCH ORAZ PROGNOZOWANIE CZASU PRACY

In the research authors suggested calculations of a mathematical computer modeling methods, of the operational reliability indicators for the freight diesel locomotives M62K, 2M62M, ER20CF, when transporting cargoes via the main lines of the Lithuanian railway network. According to the permissible values of the diesel locomotive reliability criteria, the maximum weights of a train for the studied transportation lines have been calculated and a diesel engine resource has been predicted. A methodology for reducing the dynamic indicators of the operational load cycle of a locomotive diesel has been proposed and described. When applying it, a 15÷20% reduction of load cycle's dynamic indicators (which increase the fatigue stresses of the locomotive's cylinder-piston group parts and components) is achieved. Technological recommendations are formulated, in order to increase the usage of the operational reliability indicators of diesel locomotives and their energy efficiency.

Keywords: diesel locomotive, reliability indicators, mathematical modeling, load cycle, operating time.

W oparciu o obliczenia dotyczące opracowanego z zastosowaniem komputerowego modelowania matematycznego układu w artykule przedstawiono badania porównawcze wskaźników niezawodności eksploatacyjnej silników dieslowych spalinowych lokomotyw towarowych M62K, 2M62M, ER20CF podczas kolejowych przewozów towarowych, dokonywanych głównymi liniami litewskiej sieci kolejowej. Stosując dopuszczalne wartości dla kryterium niezawodności silników dieslowych obliczono masę całkowitą pociągów na badanych liniach przewozowych oraz prognozowany rezsurs silników dieslowych. Zaproponowano i scharakteryzowano metodologię obniżenia wskaźników dynamicznych cyklu obciążenia eksploatacyjnego silnika dieslowego lokomotywy spalinowej. Dzięki jej zastosowaniu możliwe jest obniżenie o 15÷20% wskaźników dynamicznych cyklu obciążenia (zwiększających napięcia zasadniczych elementów jednostki cylindryczno-tłokowej i węzłów silnika). Sformułowano zalecenia technologiczne, mające na celu zwiększenie wskaźników niezawodności eksploatacyjnej silników dieslowych lokomotyw spalinowych oraz wykozystanie ich skuteczności energetycznej.

Słowa kluczowe: silnik dieslowy lokomotywy spalinowej, wskaźniki niezawodności, matematyczne modelowanie, cykl obciążenia, czas pracy.

1. Introduction

Nowadays Europe is facing unprecedented problems posed by transport: traffic flows increased, and predominant role was given to road transport as it appeared to be better adapted to the needs of a new economy – to transport “door to door”. Domination of this type of transport poses serious problems in Europe (traffic congestion, harmful effects on the environment and human health, threatening statistics of accidents).

In order to mitigate these problems, the Council of Europe and the European Commission have taken the following actions: to increase taxes on road transport, revive alternative means of transport (encouraging to use water and inland waterways transport, revive railways, develop multimodal transportation) [17]. Therefore the research of freight locomotives' ecological and technical indicators is gaining an increasingly greater significance.

In addition, an agreement between *International Union of Railway, UIC, Community of European Railways, CER, International Union of Public Transport, UITP* in *Union of European Railway Industries, UNIFE* to increase the railway market share in the field of passenger transportation from 6% to 10% until 2020, and in the field

of freight transportation – from 8% to 15%, as well as to reduce pollution emissions by 50% [3]. According to the “White Book”, greenhouse gas emission reduction by 40 % until 2050 became one of the main goals of the EU transport system development, including railway transport [6].

Over the past decade, the situation of railway transport in Europe has changed significantly. Railway transport potential is being developed systematically and rapidly, focusing on an increasing dependence of modern economy on transport, taking into account demand dynamics, diversity of ownership, service flexibility and the needs of engineering and technology. This has been influenced by qualitative changes that resulted from the construction of high-speed railways and new rolling stock. Railway transport has become competitive due to high speeds, comfort, a high level of service, traffic safety and ecology [9].

Considering the challenges of today, a special attention is given to the issue of railway transport infrastructure development in the Lithuanian transport and transit development strategy.

Therefore, in 2004, when Lithuania joined the European Union, the reconstruction of the Lithuanian railways and their integration into

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the European railway transport system became one of the underlying goals of the *Republic of Lithuania's Government*, at the same time preserving the useful freight and passenger transportation flows with Russia and other states of the Commonwealth of Independent States (CIS).

During the period of 2005 – 2008 the company replaced the old generation locomotives of the 2M62/M62 series with the modern locomotives of the 2M62M and ER20CF series [13].

These fleet changes allowed to significantly increase – up to 20% – the energy resource consumption efficiency and improve ecological indicators, including the reduction of greenhouse gas emissions. However, the locomotive load, significantly more intensive if compared to the Western European states, during freight transportation via the AB “LR” railway line causes unexpected failures and malfunctions of new diesel locomotives.

In order to increase the operational reliability of AB “LR” freight diesel locomotives, complex studies of locomotive operational load regime analysis and optimization have been started. An original methodology for evaluating the reliability and forecasting the operating time of a diesel locomotive has been created, which operates by the indirect criteria of mechanical and thermal load. The methodology’s adaptation to the D49, CAT3512B-HD, MTU 16V 4000 R41 type diesel engines has been carried out [12].

The publication presents the results of the diesel locomotive’s real load cycle analysis, evaluations of maximum train weight in the characteristic railway network lines, and technological proposals to increase the operational reliability.

2. Research methodology

The modelling of freight diesel locomotive parameters in the operational characteristic regimes has been done by using the computer program complex “Characteristics”, which created by the author, based on the small increment method. The functional dependences of the processes occurring in a diesel cylinder and adjacent systems are presented in the form of simple linear equations. The direct relationship between the diesel starting parameter – the increment of the objective function $y_i \delta y_i$, and the influencing variable increment δx_m that does not belong to this parameter, is measured in the form of equation system [4]:

$$\left. \begin{aligned} \Delta_{11}\delta y_1 + \Delta_{12}\delta y_2 + \dots + \Delta_{1j}\delta y_j + \dots + b_{11}\delta x_1 + b_{12}\delta x_2 + \dots + b_{1k}\delta x_k \\ \Delta_{21}\delta y_1 + \Delta_{22}\delta y_2 + \dots + \Delta_{2j}\delta y_j + \dots + b_{21}\delta x_1 + b_{22}\delta x_2 + \dots + b_{2k}\delta x_k \\ \dots\dots\dots \\ \Delta_{i1}\delta y_1 + \Delta_{i2}\delta y_2 + \dots + \Delta_{ij}\delta y_j + \dots + b_{i1}\delta x_1 + b_{i2}\delta x_2 + \dots + b_{ik}\delta x_k \end{aligned} \right\} (1)$$

Y – unknown variable parameter of diesel; X – diesel parameter influencing factor; Δ_{ij} and b_{ik} – coefficients of the variable increments’ influence on the unknown values, where n – the number of variable’s change steps.

For example, the change of indicated efficiency of diesel operation process in the function of diesel parameters is expressed as follows:

$$\Delta \eta_i = K_{\alpha \eta_i} \Delta \bar{\alpha} + K_{\varepsilon \eta_i} \Delta \bar{\varepsilon} + K_{\lambda \eta_i} \Delta \bar{\lambda}, \quad (2)$$

(when the invariability of revs and air density against the cylinder exist $n, p_k = \text{const}$).

where: $\Delta \bar{\alpha}, \Delta \bar{\varepsilon}, \Delta \bar{\lambda}$ – relative increments of independent variables (excess air coefficient, compression ratio, pressure in the cylinder increase ratio);

$K_{\alpha \eta_i}, K_{\varepsilon \eta_i}, K_{\lambda \eta_i} - \alpha, \varepsilon$ and λ influence coefficients for the indicated efficiency η_i .

The influence coefficients are measured by summarizing the wider results of the experimental medium and high rev diesel testing, and during the modeling process the coefficients are adjusted according to the technical features of the studied object.

Equation system (1) of each independent variable is solved in the following sequence: by using the initial x_{ko}, y_{jo} data, that corresponds to the diesel operating in the maximum power regime, the influence of its digital values on the coefficients Δ_{ij} and b_{ik} is measured; the values of the equation right sides for the given relative increments δx_k are calculated; the equation system roots are calculated; new unknown values of the variables are calculated according to the formula $y_j = y_{jo}(1 + \delta y_i)$.

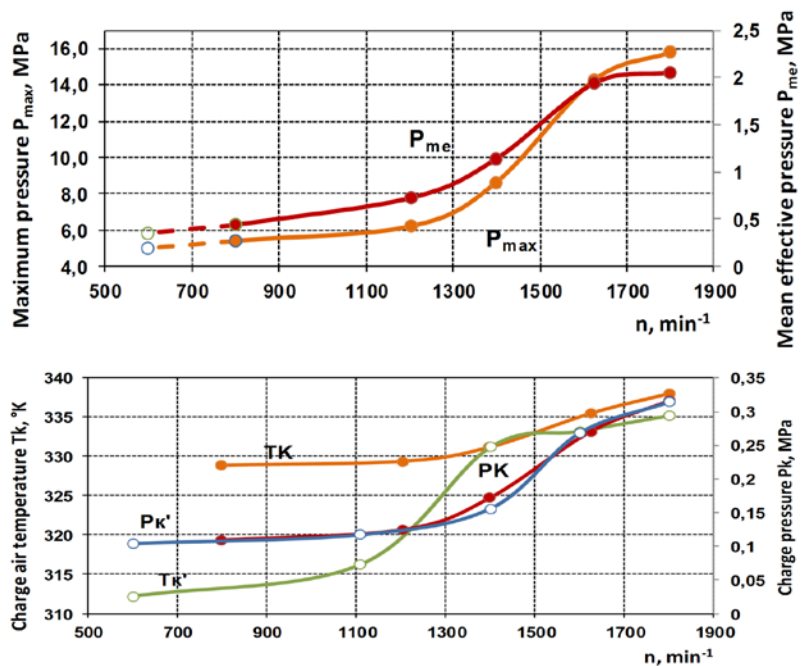


Fig. 1. Operation parameters of the MTU 16V4000R41 diesel locomotive (o – experimental data of the manufacturing company’s bench tests; • – results of mathematical modeling)

The basis of the analytical description of the processes that occur in the diesel systems consists of the classical theory of internal combustion engines supplemented by the experimental study results. The physical processes in the cylinder and adjacent systems is regarded as quasi-stationary. The adopted assumptions ensures calculation accuracy sufficient for solving practical problems [9, 11, 18].

According to the modeling of diesel maximum power regime parameters, the tune-up of the 14D40, 2-2D49, Caterpillar 3512B HD-SC, MTU 16V4000R41 diesel inflator units and the air debit characteristics of the piston part, as well as the operational modeling of the locomotive characteristics has been carried out. Fig. 1 shows the result examples of modeling the 16V4000R41 diesel energy indicators and operation process parameters according to the crankshaft revs n (diesel locomotive ER20CF).

The range of independent variable variation is divided into small increments – calculation steps. At the end of each calculation step the values for diesel indicators are measured, according to which the new values of influence coefficients are calculated for the next step. Relatively small calculation steps, not exceeding 5% of a parameter’s

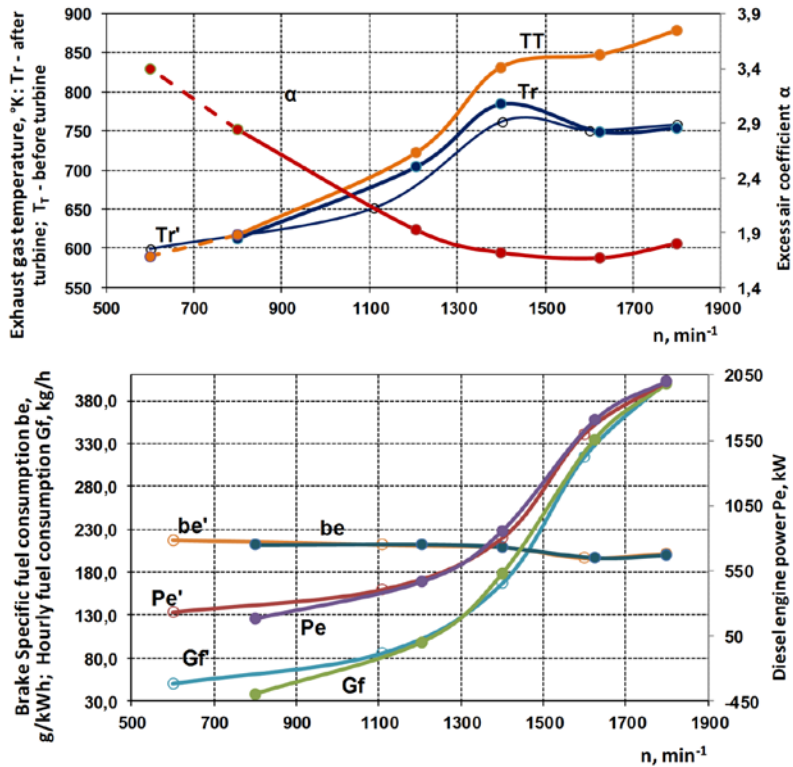


Fig. 1. (continued)

variation range, allows to significantly reduce the calculation error.

The adequacy of the mathematical modeling is confirmed by comparing the calculation and experiment data. The difference between the experiment and mathematical modeling results, not exceeding 3÷5 %, is regarded as perfectly acceptable for solving the practical problems defined in the studies. The methodological basis for the research of the diesel locomotive reliability indicators and operating time (projected resource) consists of computer experiment carried out in accordance with the original methods created by the authors. The parameter arrays of the traction characteristics of the locomotives operated by JSC Lithuanian Railways (hereinafter - JSC LR) in the main railway network lines have been used for the initial modeling data, when the train weight is from 3000 t to 7500 t. The traction characteristic parameters of JSC LR are measured by modeling with computer the freight transportation in real railway network conditions [12]. According to the modeled operational characteristics of a locomotive's diesels, the energy and operation process parameters, reliability indicators, as well as the projected resource based on them, are calculated for each elementary step (according to the trip time interval and road distance).

The projected resource of a locomotive's diesel engine may experience a 10 % higher decrease than stated by the manufacturing company. Such a conclusion was made basing on the following reasons: the confidence range of the analytical dependencies measured between the indirect criteria of the thermal, mechanical load and diesel engine resource is around 5 % (when measuring the determination coefficient values 0.96–0.97); by adding the additional 5 %, the error of the diesel parameter mathematical modeling

according to the traction characteristics of locomotives is taken into account.

3. Research results

3.1. The change of diesel indirect load criteria

The following indirect criteria were used in the work [5, 11]:

- $\zeta = P_{\max} \left(\frac{1}{\alpha}\right)^{0.8} (P_K \cdot c_m)^{0.5} n$ – Prof. Kostin criterion

(applied to transport diesels, measures the thermal and mechanical load of parts according to the operation process parameters);

- $q_I = \left(\frac{1}{\alpha}\right)^{0.8} (P_K c_m)^{0.5}$ – Prof. Kostin criterion (applied to the diesels of various use and types, measures specific heat flow to the bottom of a piston and head of a cylinder according to the operation process parameters);

here: P_K – charge air pressure, MPa; α – excess air coefficient; c_m – average speed of a piston, m/s; maximum cycle pressure P_{\max} , MPa.

The change of the ζ or q_n criteria for the locomotive's old generation diesels 14D40 (for comparison), the modernized 2-2D49, modern Caterpillar 3512B HD-SC and

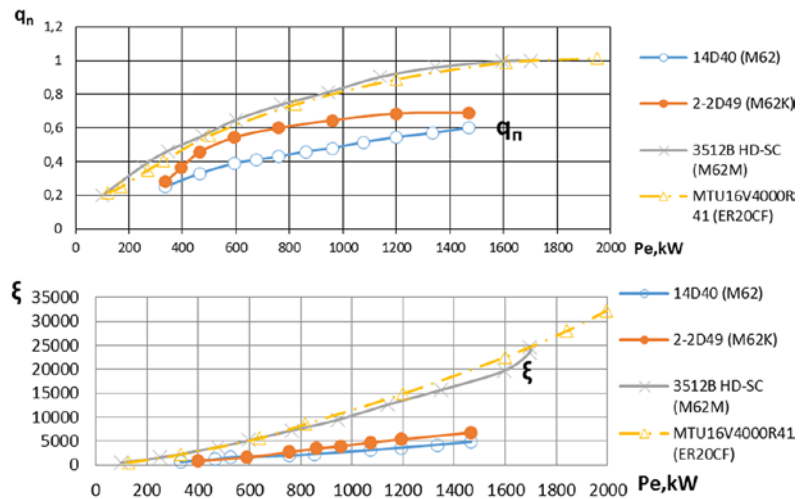


Fig. 2. The change of a locomotive's diesel indirect load criteria P_d , ζ in the operational characteristic modes

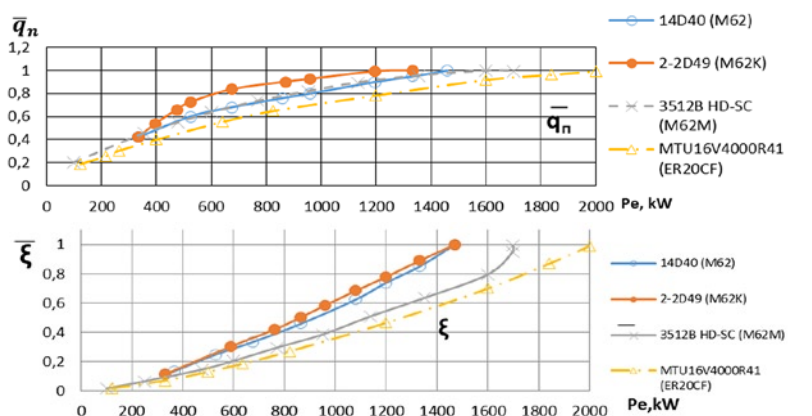


Fig. 3. The change in relative form of a locomotive's diesel indirect load criteria ζ , q_n in the operational characteristic modes

MTU 16V4000R41 models, according to the effective (used) power of an engine P_e , is shown in the absolute graphical form in Fig. 2, in the relative form (the ratio of a criterion with its maximum value) – in Fig. 3. The change of criteria reflects the thermal and mechanical load variation degree for the diesel parts, when the diesel operates in the locomotive characteristic modes.

These criteria dependencies are used in the authors' methodology by measuring the current and average load of the diesel parts in the operational cycle, as well as the predicted operating time based on the load (by comparing with the standardized UIC load cycle [3]). In order to measure the operating time, the relative criteria indicators from their maximum values in the nominal load regime have been used. E.g., the relative change of the ζ criterion

$$\Delta\zeta = \left[\frac{\zeta_f - \zeta_{UIC}}{\zeta_{100\%}} \right] \cdot 100\%, \text{ where } \zeta_f - \text{average trip}$$

value of a criterion according to the real load cycle; ζ_{UIC} – value of a criterion according to the standardized UIC load cycle.

The analysis of the relative criteria values' change dynamics (Fig. 3) confirms the following:

- the variation of the effective engine power has a greater power of influence on both thermal and mechanical criteria, as well as on the operating time of the 14D40 and 2-2D49 diesels compared to the Caterpillar 3512B HD-CF and MTU 16V4000R41 diesels;
- the criteria variation dynamics of approaching the parabolic dependence, as well as a several times bigger criteria variation range from idle to nominal diesel power, means a lower influence of the Caterpillar 3512B HD-CF and MTU 16V4000R41 diesel effective power variation.

According to the results, it is advisable to form the operational load cycle structure of the new-generation diesel locomotives (Caterpillar 3512B HD-CF, MTU 16V4000R41) from the average load regimes, by limiting the duration of the nominal power and idle regimes as much as possible. This hypothesis is proved by conducting the mathematical modeling research.

High determination coefficients $R^2 = 0,91 \div 0,98$ of the diesel engine resource (T) and criteria (ζ , q_n) interrelationship gives evidence about the adequacy of applying the criteria in researches [10]. For further mathematical modeling research, the equivalent criteria ζ and q_n have been chosen.

3.2. Creating program complex for mathematical modeling of the ζ and q_n criteria in operational conditions.

When creating program complex, one of the main adopted provisions is its functionality compatibility with the IT software solutions (for modeling train trips when transporting cargo and for making schedules) used by JSC LR in practice.

The structure of the created program complex consists of 3 inter-related functioning software blocks:

- block for scanning and processing the modeling data of the locomotive traction parameters during trip;
- block for setting the current (time interval discretion during trip) operational mode (power - diesel rev combinations) of a diesel locomotive, basing on the current values of diesel parameters, as well as for calculating the reliability indicators;
- block for the statistical processing of indirect diesel reliability indicators, measured during a trip, and energy parameter data

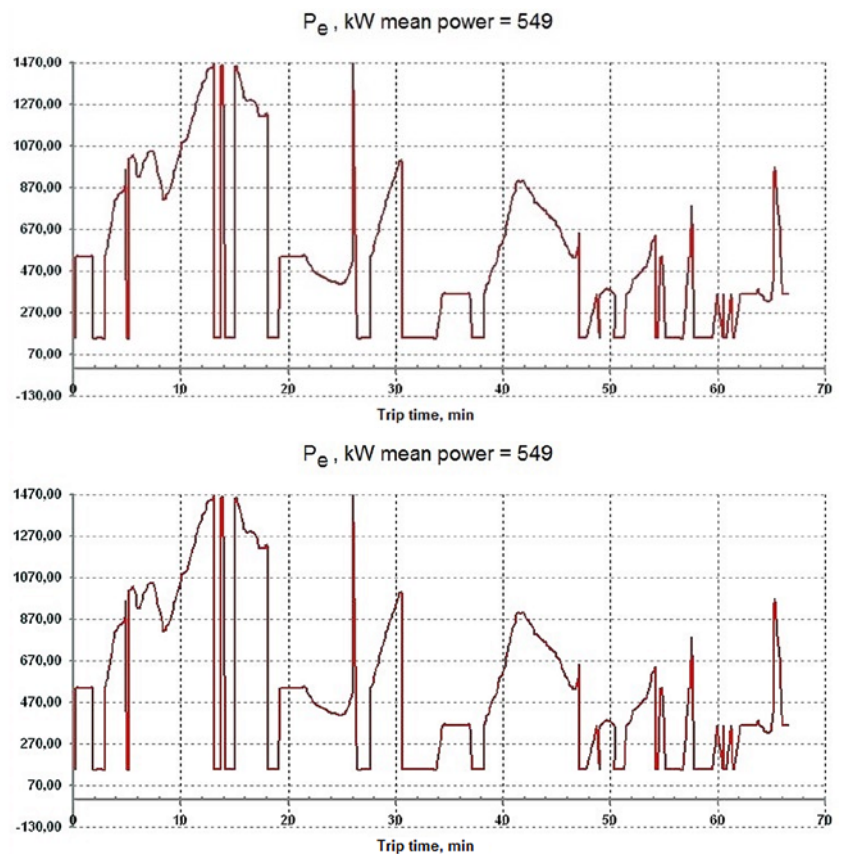


Fig. 4. The load cycle structure of the 2M2K locomotive in the Kena-Vaidotai line a) current values; b) P_e value distribution during a trip

arrays. This block is meant for showing the current destinations in a graphical form, for calculating the average trip values of diesel parameters and the structure of operational load cycle - the distribution of the indirect reliability indicators and energy parameter values according to the duration of a trip (Fig. 4).

For convenience purposes, the modeling results and the indicators of their statistical processing are presented by a data array and in a graphical form in a computer screen.

The possibility of the created program complex functioning is not limited to the evaluation of diesel locomotives' reliability indicators and the prediction of their resource. This program complex can be used for effectively performing the tasks of operated diesels' energy resource efficiency and increasing energy use efficiency, as well as decreasing the environmental pollution with diesel engine oxides.

In prospect, it is expected to be used in order to achieve complex optimization of trip parameters according to the above-mentioned parameters.

3.3. Modeling the operational load of the diesel locomotives' rational structure.

With the help of the created program complex, the criterion of the maximum train weight has been calculated according to the reliability criteria. A condition has been set that the predicted diesel resource (R_2) would not decrease by lower than 10 % compared to the operating time data stated by the manufacturing company. In order to improve the adequacy of the maximum train weight measurement, the relative changes $\Delta\zeta$ (hereinafter marked as ΔK_2) of the ζ criterion has been used further in the analysis.

According to the found analytical dependencies between the indirect and operating time [12], the ΔK_2 values have been recalculated to the relative changes of diesel resource duration $\overline{R_2}$, %.

Table 1. Limitations for train weight according to the diesel locomotive reliability criteria

Locomotive type	Freight transportation line			
	Kena–Vaidotai–Radviliškis (197,3 km)		Radviliškis–Klaipėda, Draugystė (via Kužių st.) (198,9 km)	
	Train weight, t		Train weight, t	
	M_1	M_2	M_1	M_2
2M62K	4000	4000	4200	3800
2M62M	5500	5000	6000	4800
ER20CF	3500	4000	3800	3800
2ER20CF	7500	7500	7500	7500
Locomotive type	Kena – Vaidotai – Radviliškis (197,3 km)		Radviliškis – Klaipėda (via Pagėgių st.) (229 km)	
	Train weight, t		Train weight, t	
	M_1	M_2	M_1	M_2
2M62K	4000	4000	4500	4000
2M62M	5500	5000	6000	5000
ER20CF	3500	4000	3500	4000
2ER20CF	7500	7500	7000	7000

M_1 – maximum weight recommended according to the diesel reliability indicators

M_2 – “train weight calculated according to the power of a section locomotive” (JSC LR traffic schedule 2011/2012).

The results of the carried out mathematical modeling research allowed to evaluate the maximum train weight limits used in practice by JSC Lithuanian Railways in accordance with the locomotive's traction (M_2), and in parallel to calculate the train weight, basing on the diesel locomotive reliability criteria (M_1) in the main Lithuanian railway lines. As a result, proposals have been formulated for rational formation of train weights in respect of diesel locomotive reliability (without decreasing the resources stated by the manufacturers).

For example, Table 1 shows freight transportation modeling results for one of the lines: Kena – Vaidotai – Radviliškis – Klaipėda, Draugystė.

As the research results show, the 2M62K and 2M62M diesel locomotives have a reserve according to the allowable load in the Radviliškis–Klaipėda, Draugystė (via Kužių st.) section, and train weight can be increased from 3800 t to 4200 t and from 4800 t to 6000 t respectively. In other words, the maximum weight of a train is limited by the locomotive traction characteristic, and the reliability criteria have not reached their limit values.

The locomotive load on equal terms in the Radviliškis–Klaipėda (per Pagėgių st.) section is not very different from that of the alternative sections: when using the 2M62K and 2M62M locomotives, the train weight has a 500 t reserve for an increase, while the train weight of the ER20CF locomotive should be reduced by 500 t to 3500 t, in order to achieve reliable operation and the stated resource of the diesel locomotive.

3.4. Increasing the locomotive's operational efficiency indicators by optimizing the load cycle structure.

The created computer program complex is described by ample possibilities for structural analysis of the diesel operational load cycle. The its functioning possibilities allow to analyze and improve the reliability, energy, ecological and other indicators by modeling real operational conditions (the profile of freight transportation and freight transportation line, regulated speed limits in sections etc.).

In the current research phase, the structural analysis of JSC LR freight locomotive diesel load cycle has been done, technologies for reducing the technological dynamics of the transient processes have

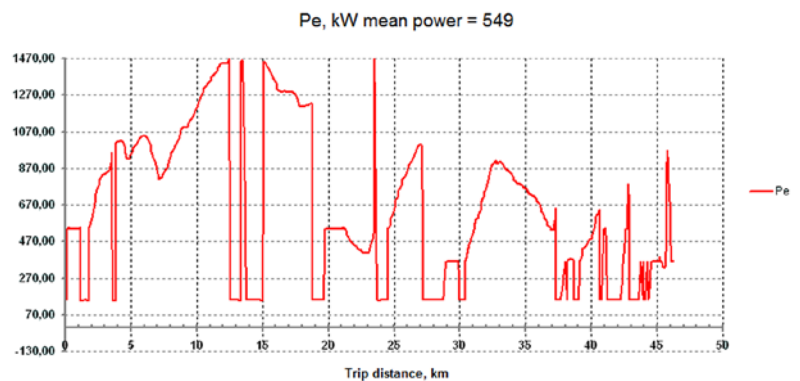


Fig. 5. The load cycle structure of the 2M2K locomotive in the Kena–Vaidotai line

been formulated and approved, as a result of which the diesel operational reliability indicators and fuel efficiency indicators can be improved.

The studies have shown that the diesel locomotive load does not exceed 30–35 % of their nominal power in certain transportation lines (e.g., Kena – Vaidotai, Fig. 5). The diesel load spectrum mostly involves the regimes with power, that makes up 20–30 % and 30–40 % of the nominal power and idle (25–30 % of the operational cycle duration), when the diesel locomotive transports cargoes.

At the same time the D40 and D49 diesel locomotives reach 100 % of power (1470 kW) for short-term periods in the sections of up to ~25 km length and 12–15 km on average, the maximum power in other sections of the line does not exceed 970–1000 kW. The sudden change in the load cycle is known to increase the indicators of the transient diesel operational process dynamics, worsen energy ecological and reliability parameters [1, 7, 10, 19]. On this basis, in order to increase diesel operational efficiency, the program complex possibilities have been used to carry out the analysis of JSC LR diesel locomotive load cycle structure and the evaluation of the parameter change influence.

The diesel load cycle spectrum in another line: Vaidotai–Kybartai notably different. The MTU 16V4000R41 diesel with high crankshaft rev frequency (train weight 7000 t) of the 2ER20CF locomotive changes load from 100 % of the nominal idle condition (Fig. 6). The

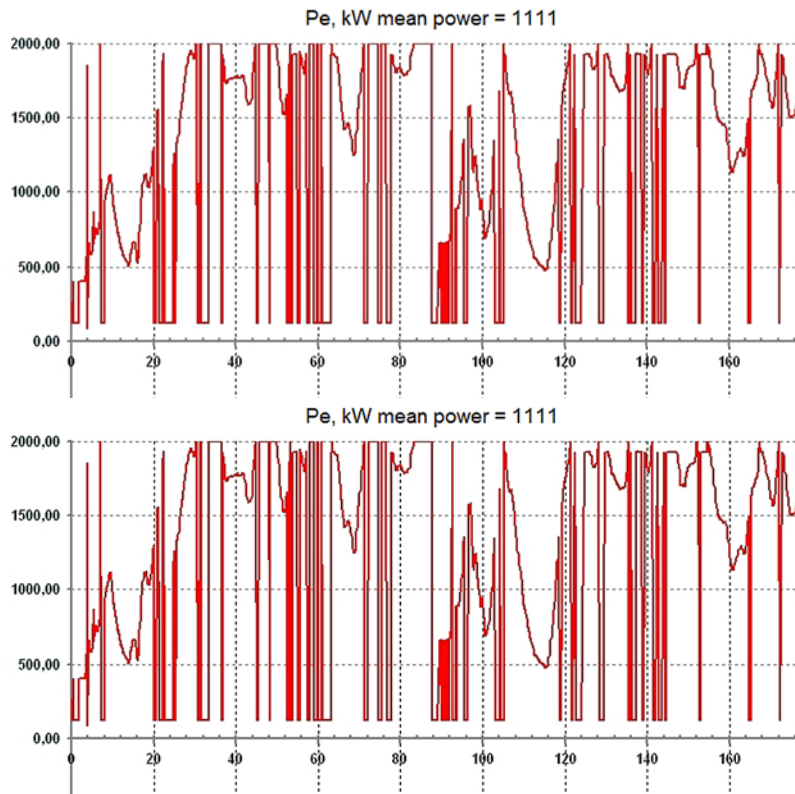


Fig. 6. The load cycle structure of the 2ER20CF locomotive in the Kena–Kybartai (50–60 km) line

average load $P_{e\ vid} \approx 55\%$ or 1111 kW. The increased scale of the load cycle spectrum allows to analyze in more detail the dynamic load indicators in specific parts of a section, e.g. 50–60 km (Fig. 6). It is obvious that the use of surplus diesel power (compared to the necessary power in order for a train to reach certain speed) in a part of the line creates a necessity to put the diesel in idle condition next time, thus increasing the dynamic indicators of load variation: amplitude and frequency.

Such sequence of the change in diesel locomotive load regimes is also typical to other models of the locomotive fleet operated by JSC LR. When transporting cargoes via relatively short lines of difficult profile with many speed limits. When transporting cargoes at high speed via the long lines [14, 16], the nominal diesel locomotive load is fully justifiable. This transportation technology in Lithuanian conditions, where the maximum length of railway network lines is 200–250 km, is debatable.

One of the available ways of reducing the excess load cycle dynamics is the reduction of transport speeds, accordingly limiting the maximum diesel load in operation. The increase in trip time of 15–20 min., calculated by modeling, is not critical. From the technological perspective, this method could be realized by reducing the locomotive traction, limiting the maximum diesel load (the controller positions). It is obvious that the traction limitations are possible when the train weight is lower than the maximum weight in specific transportation line for certain locomotive type.

Table 2. The influence of limiting the traction of the 2M62M locomotive in the Vaidotai – Kybartai line on the diesel load spectrum parameters

Train weight, t	Traction limitation coefficient	P_e maximum short-term value, kW	P_e maximum long-term value, kW	Trip duration increase, min.
4000	1	1600	1200	-
4000	0.83	1350	1150–1200	6
4000	0.67	1300	1200–1250	15.5

Table 3. The traction limitation for the 2ER20CF locomotive in the Bugeniai–Klaipėda, Draugystė line influence on diesel energy and reliability indicators

Train weight, t	Traction limitation coefficient	$P_{e\ vid}$, kW	$G_{f\ vid}$, kg/h	R_2 , mh	ΔK_2 , %	T_L , min	V_{vid} , km/h	Load variation frequency, %
4800	1	955	194	45200	5	199	68.4	100
4800	0.64	798	164	48750	-3.6	229	59.5	~75
Variation of parameter	-36%	-17%	-16%	+7%	-8.6%	+30	-8,9	-

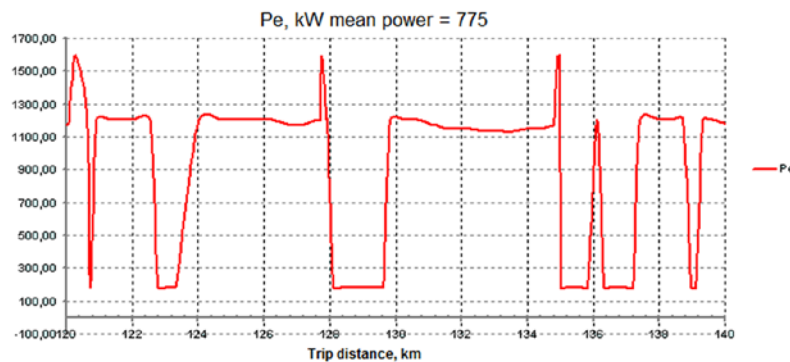


Fig. 7. The load cycle parameters of the 2M62M locomotive in the Vaidotai–Kybartai line: a) without traction limitation; b) traction limitation coefficient 0,83; c) traction limitation coefficient 0,67

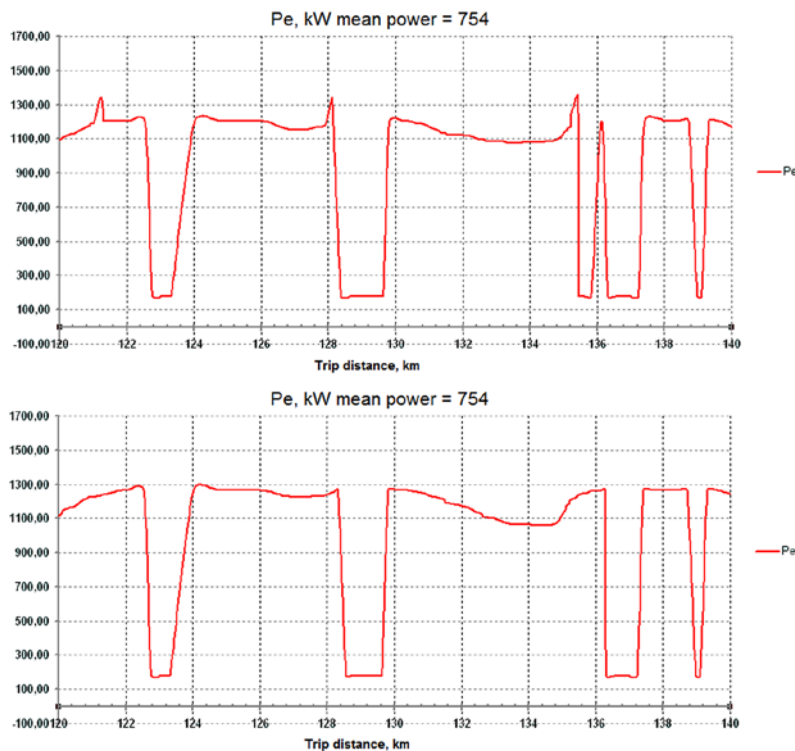


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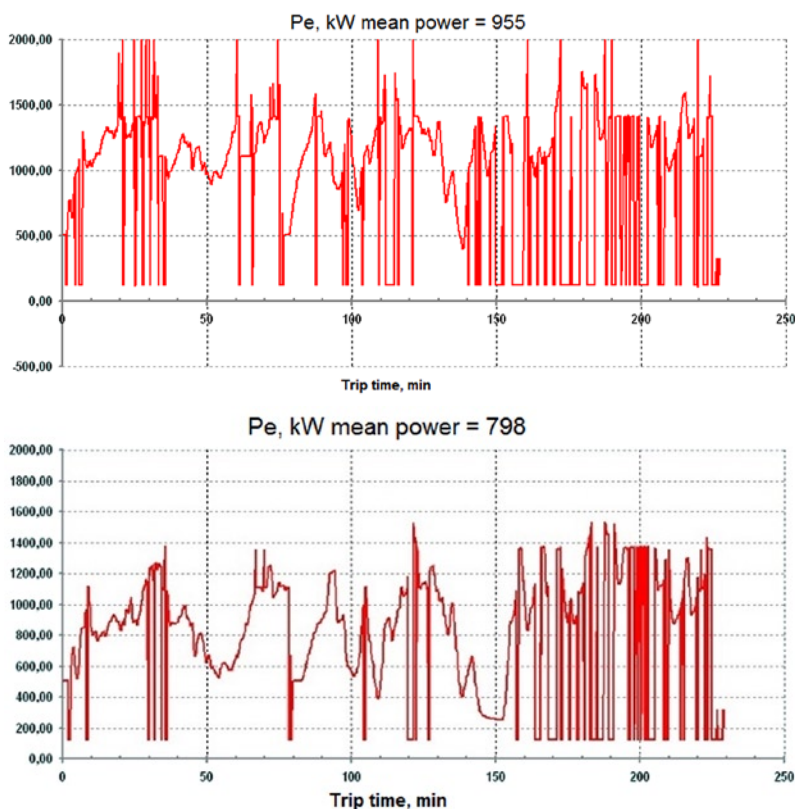


Fig. 8. The load cycle structure of the 2ER20CF locomotive in the Bugieniai–Klaipėda, Draugystė line: a) without traction limitation; b) traction limitation coefficient 0,64

3.5. Evaluating the efficiency of locomotive traction limitation

The influence of locomotive traction limitation on diesel op-

erational parameters fundamentally depends on the transportation line profile and diesel operational characteristic. In some cases the effect of the increase in reliability and energy indicators is significant, in other cases - close to zero. But in all cases a parameter, important for the diesel operational reliability indicators, is reached - the load spectrum is "equalized", the dynamics of transient processes are reduced. Thus, after reducing the traction by 34 % for the 2M62M locomotive in the Vaidotai–Kybartai line, the main diesel operational indicators practically remained unchanged, while the trip duration increased by 15,4 min. (when the speed decreased from 64,6 km/h to 59,2 km/h). Yet the load spectrum amplitude decreases as well (table 2, Fig. 7).

The amplitude of the change in diesel power decreased from 1400 kW to 1100 kW or by 22 %. At the same time the P_e variation frequency also decreased (e.g., in the analyzed part of the line - by around 30 %). As a result, the load of cylinder - piston group parts, the ones that experience the highest mechanical loads - aluminum shaft and crank, decreased and the resource increases accordingly [15].

Even more significant positive effect is achieved by limiting the traction characteristic of the 2ER20CF locomotive (train weight 4800 t, see table 3). The load spectrum has shifted to the area of average power, along with a decrease of the operating time in the nominal power and idle regimes (Fig. 8).

The power variation amplitude decreases significantly: from 2000 kW to 1400–1500 kW, the variation frequency decreased approximately two-fold. The power variation amplitude decreased from 1880 kW to 1280 kW, i.e. by 32 %, while the short-term increase in P_e disappears entirely. The load variation frequency decreased by ~ 25 %.

After diesel operational power during a trip has decreased, the hourly fuel consumption also notably decreases (~16 %) but fuel costs, due to the increase in trip duration (~15 %), practically remains the same.

The achieved result is no less important – in all studied cases of traction characteristic limitation the trip duration increased up to the level which is typical for the transportation of maximum-weight (M_1) cargoes. This fact is regarded as positive as, when applying the proposed traction limitation technologies, the freight transportation schedule, made on the basis of marginal mass, is not changed anymore. Favorable conditions appear which allow to unify the trip durations of certain-type locomotives that transport cargoes via certain lines.

4. Conclusions

The methodology for evaluating diesel operational reliability indicators of the JSC Lithuanian Railways locomotive and predicting its operating time has been formed, on the basis of which the computer program complex for mathematical modeling has been created. In the program complex, the functioning possibilities have been realized, that allow to perform the statistical analysis of the operated diesel locomotive reliability indicators, energy parameters and load cycle parameters, in order to achieve their cross-compatibility and optimization:

1. By applying the program complex for mathematical modeling to the freight locomotives of JSC Lithuanian Railways, the maximum weight (M_1) of up to 10-15 % of trains in the characteristic railway network lines according to the 14D40, 2-2D49,

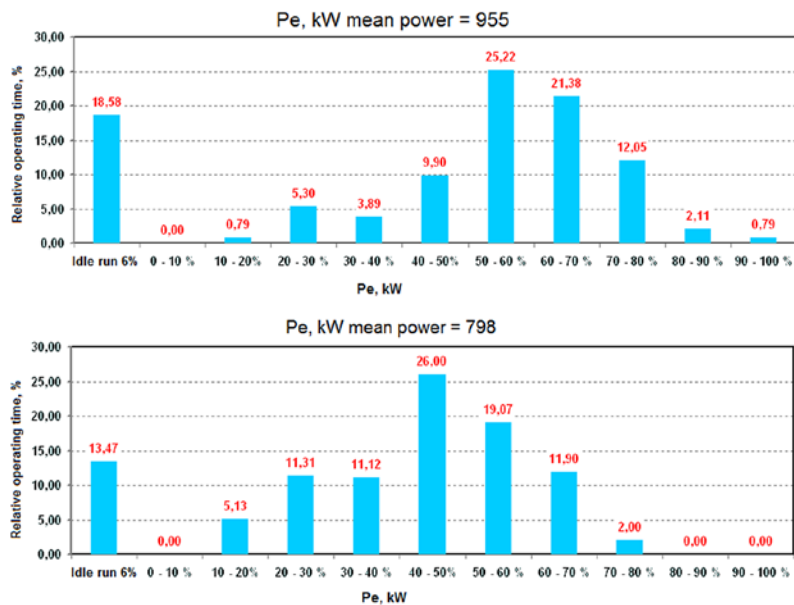


Fig. 8. The load cycle structure of the 2ER20CF locomotive in the Bugieniai–Klaipėda, Draugystė line: a) without traction limitation; b) traction limitation coefficient 0,64

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Caterpillar 3512B-HD-SC, MTU 16V4000R41 diesel locomotives, the allowable mechanic and thermal load of their parts.

2. The methodology for decreasing the dynamic indicators (that worsen reliability, energy and ecological diesel characteristics) of the thermal diesel operational load cycle has been proposed and, using the mathematical modeling research, approbated; based on its practical application, the following is predicted:

- to lower the diesel engine load, diesel locomotive resource by 7–10 %, without the increase in fuel costs of a trip;
- reduction of load cycle indicators (diesel power variation amplitude and variation frequency) by up to 20–25 %.

In all studied cases of locomotive traction characteristic limitation the trip duration increased by no more than 20-30 min up to the level which is typical for the transportation of maximum-weight (M1) cargoes. When applying the traction limitation technology, favorable conditions appear which allow to unify the trip durations of freight locomotives.

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