Substantiation of logistical indicators of diesel traction loco-motives use in the high-speed railroad section

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Abstract. The paper presents the results of research on the justification of parameters of transport operation of three-section main (train) UzTE16M3 freight diesel locomotives on the high-speed railway section Marokand-Kattakurgan of JSC "Uzbekistan Temir Yullari" when moving freight trains without stops and with stops at intermediate stations, passing points, and separate points. The specified results were obtained by methods of locomotive traction theory in the form of tabular data, graphical dependences, and regression equations for determining logistical kinematic parameters of freight train traffic and the main energy efficiency indicators of the investigated diesel locomotives in a given section. The research results obtained by the authors can be used by drivers - instructors in thermal engineering and specialists of linear enterprises of JSC "Uzbekistan Temir Yullari" locomotive complex, whose professional and production activity is connected with the issues of saving of natural diesel fuel consumption by diesel locomotives on high-speed sections of the railroads.

1 Introduction

Nowadays, Uzbekistan's high-speed passenger railroad with a total length of 741 km, consisting of three high-speed sections Tashkent-Samarkand, Samarkand-Karshi, and Samarkand-Bukhara, is served by six Afrosiyob electric trains and passes through seven regions of the republic, connecting such major cities as Tashkent, Samarkand, Bukhara, Karshi and Navoi.

Besides, on the above high-speed sections of the Uzbek Railways, freight and passenger rail transport is universally carried out by electric (electric locomotives of VL60K, VL80S, and "Uzbekistan" series) and diesel (diesel locomotives of TEV10M, UzTE16M and TEP70 series) traction in different sectional designs.

At present, JSC "Uzbekistan Temir Yullari" has actively carried out an increase in the fleet of diesel traction locomotives through a phased deep modernization of several existing mainline (train) freight locomotives of TE10M series by replacing the diesel engine 10D100
with a "new" advanced diesel engine 1A-5D49 PO Kolomensky Teplovozostroitelny factory.

An analysis of the data [2] shows that approximately 52.6 percent of all the sections of the JSC UzTE16M locomotive fleet are mainline (train) freight locomotives with diesel traction, and about 30.0 percent of them are UzTE16M series freight locomotives in various sectional designs.

Research to improve the efficiency of diesel and electric traction locomotives in real conditions of organization of different types of traffic on high-speed railroad sections is a paramount task for energy efficiency of mainline traction rolling stock of the locomotive fleet on the specified sections.

This is solved as a result of comprehensive measures by finding ways and opportunities to implement the aforementioned efficiency, based on various organizational and technical, design, and technological developments.

2 Materials and Methods

The analysis of scientific research by scientists of the far abroad [3-15], conducted by the author [16,17] for traction diesel and electric rolling stock, including high-speed, testifies that in modern theoretical research only a few of them consider questions of realization of the practical component directed on increase of efficiency of use of locomotives. Indeed, only the works [6,7,15] substantiate and recommend various technical and design-technological solutions to ensure the possibility of reducing the consumption of fuel and energy resources for the movement of freight trains, primarily by diesel and hybrid traction locomotives, to the practice of linear enterprises of the railroad network.

In addition, the results of studies [3-15], having a certain scientific interest and practical significance, are not interrelated with the justification of the parameters of the main indicators of energy intensity of transportation and efficiency of traction rolling stock as applied to the real conditions of the organization of freight traffic on the high-speed railway sections of the Uzbek railroads, taking into account the complexity of their track profile.

To analyze and assess the fuel and energy efficiency of mainline (train) freight diesel traction locomotives under various operating conditions on high-speed railroad sections, it is possible and necessary to use the main logistical indicators of transport energy-kinematic parameters of freight train movement, quantitative and cost values of total and specific consumption of natural diesel fuel for train traction. The aforementioned kinematic parameters are the speed of movement and travel time of a freight train in the studied section in different modes of operation of the locomotive power unit.

The present studies continue the work [1,2] and are devoted to the study of traffic conditions of three-section main (train) freight locomotives UzTE16M3 series when they drive freight trains in real operating conditions of a given (adopted by us) high-speed railway section Marokand-Kattakurgan Uzbek railroad.

The purpose of this study is to justify the logistical performance of mainline (train) freight diesel traction locomotives on the high-speed, hilly-mountain section of the Uzbek railroad-the kinematic parameters of freight trains and the main fuel and energy efficiency indicators of locomotive transportation work in quantitative and monetary calculations.

In order implement the formulated research goal, an appropriate algorithm [16] of traction calculations, the basis of which are methods and techniques of the theory of locomotive traction, initial data, object, and subject of research [17,18].

The object of the study-freight trains with different weights of the train and the same number of axles in the composition, three-section main (train) freight locomotives series UzTE16M3, as well as the hilly-mountain profile track of the high-speed section Marokand-Kattakurgan Uzbek Railways.
The subject of the study is the logistical kinematic parameters of freight train traffic without stops and with stops at intermediate stations, passing points, and separate points, and the main fuel and energy efficiency indicators of the studied diesel traction locomotives in quantitative and monetary calculations on a given high-speed railroad section.

Traction and energy characteristics of the studied freight locomotives UzTE16M3 about their design features are described in detail in [17], and a detailed characterization of the straightened profile of the hilly-mountainous, high-speed section Marokand-Kattakurgan is given in [18].

3 Outcomes and Discussion

Table 1 indicates the logistical performance of three-section main (train) UzTE16M3 freight locomotives on the high-speed Marokand-Kattakurgan section when running freight trains without stops and with stops at intermediate stations, passing tracks, and separate points. In addition, this table also shows the average and averaged values of the parameters of the above parameters for both (two) types of traffic, and the latter were calculated (defined) as the arithmetic mean values in the range of changes in the weight of trains (from \(Q_1=2500\ t\) to \(Q_3=3500\ t\)) of freight trains.

Evaluation of the qualitative component of the transportation work of three-section main (train) freight locomotives UzTE16M3, carried out during the implementation in the freight traffic of railway transportation of different types and types of cargo on a given, high-speed railway section Marokand-Kattakurgan JSC "Uzbekiston temir yullari" was conducted by comparing the average and averaged values of the above logistical indicators.

Table 1. Main logistical indicators of transportation performance of UzTE16M3 diesel locomotives on the high-speed Marokand-Kattakurgan section of the Uzbek Railway

<table>
<thead>
<tr>
<th>Traction calculation option</th>
<th>Conditions of transportation work</th>
<th>Running time of the train, min</th>
<th>Diesel consumption</th>
<th>Expenditures of cash</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mass of the train (Q_t), t</td>
<td>number of axles (m), axles</td>
<td>technical speed (V_t), km / h</td>
<td>in mode draught (e_t), mm</td>
</tr>
<tr>
<td>1 2500</td>
<td>200</td>
<td>69.96</td>
<td>7.80</td>
<td>4.3</td>
</tr>
<tr>
<td>2 3000</td>
<td>200</td>
<td>70.41</td>
<td>7.75</td>
<td>4.4</td>
</tr>
<tr>
<td>3 3500</td>
<td>200</td>
<td>67.37</td>
<td>8.10</td>
<td>5.3</td>
</tr>
</tbody>
</table>

Movement along the sections, without stopping

Marokand – Juma crossing \(L = 8.75\ km\)

Juma – Nurbulak crossing, \(L = 29.00\ km\)

Nurbulak – Kattakurgan crossing, \(L = 24.00\ km\)

1 2500 200 69.35 20.90 4.25 16.65 107.75 17.84 25.51 190.76 7.897

2 3000 200 67.73 21.40 4.50 16.90 113.59 15.67 22.41 201.10 8.325
The analysis of the data provided in Table 1 for the average and averaged values of the main logistical indicators of the UzTE16M3 locomotives under operation conditions on the hilly-mountain, high-speed Marokand-Kattakurgan section testifies to the following:

- increase in the efficiency of transport operation of the investigated diesel locomotives is provided by the mode of movement of freight trains without stopping at separate points;
- reduction in the consumption of full-scale diesel fuel per trip is directly related to a decrease in the work of the power plant of the studied diesel locomotives under load and an increase in the movement time of the freight train in idling and braking modes, which leads to a decrease in the mechanical forces acting on the mentioned train in the traction mode;
- an increase in the weight of the train and the operating time of the power units of the investigated diesel locomotives in the traction mode leads to an increase in the amount of diesel fuel consumed and a decrease in the mechanical work of the forces acting on the freight train in the idle running and braking modes;
- the increase in the volume of transportation work of the investigated diesel locomotives contributes to improving the efficiency of their use regardless of the type of cargo transported and the type of freight train traffic;
- Each successive reduction in the weight of the freight train composition by the value of \( \Delta Q = 500 \text{ tons} \) leads to a reduction in the cost of rail freight transportation and an increase in the specific diesel fuel per train traction;
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By processing in the Microsoft Excel Office environment the values of the parameters of the main logistic indicators of fuel and energy efficiency of the use of the studied diesel locomotives UzTE16M3 on the Marokand-Kattakurgan section, similarly to studies [1,2,17], the corresponding analytical expressions (regression equations) were obtained, designed to calculate the average values of the mentioned parameters in real conditions of organization of freight traffic on a given high-speed railway section Marokand-Kattakurgan, implemented by three-section main (train) freight diesel locomotives of the UzTE16M3 series of any \( i \)-the mass of the \( Q_i \) train of a freight train with a sufficient approximation reliability value \( R^2 = 1.0 \) (necessary condition reliability- \( R^2 \geq 0.8 \)). Here the factor (indicator) \( Q_i =1,2,3 \) is a variant of traction calculation.

Total running time of the train \( t_x, \text{min} \):

\[
t_x = -0.37Q_i^2 + 2.28Q_i + 52.39
\]

Travel time in traction mode \( t_t, \text{min} \):

\[
t_t = 0.22Q_i^2 + 0.22Q_i + 15.03
\]

Train travel time in idling and braking mode \( t_{xx,t}, \text{min} \):

\[
t_{xx,t} = -0.6Q_i^2 + 2.1Q_i + 37.32
\]

Technical speed \( V_t, \text{km/h} \):

\[
V_t = 0.72Q_i^2 - 4.07Q_i + 72.41
\]

Total consumption of full-scale diesel fuel per trip \( E, \text{kg} \):

\[
E = 4.625Q_i^2 + 6.155Q_i + 366.52
\]

Specific consumption of full-scale diesel fuel \( e, \text{kg} / 10^4 \text{ t km gross} \):

\[
e = 0.645Q_i^2 - 4.935Q_i + 28.73
\]

Specific consumption of full-scale diesel fuel \( EU, \text{kg} / 10^4 \text{ t km gross} \):

\[
EU = 0.92Q_i^2 - 7.704Q_i + 41.06
\]

Total cash costs \( St, \text{thousand sums} \):

\[
St = 8.185Q_i^2 + 10.915Q_i + 648.88
\]

Presented monetary costs \( st, \text{thousand sums/km} \):

\[
st = 0.135Q_i^2 + 0.165Q_i + 10.52
\]

The analytical dependences (1)-(9) obtained by the authors agree well with the studies [1,2,17-18] and confirm that the averaged parameters of the main logistical indicators of the efficiency of the above-mentioned UzTE16M3 diesel locomotives on the high-speed railway section Marokand-Kattakurgan of JSC "Uzbekiston temir yullari" change according to the polynomial law when increasing and decreasing the weight of the freight train.
Logistical kinematic parameters of freight train movement and energy parameters of efficiency of use (transportation work) of three-section main (train) UzTE16M3 freight locomotives about the distribution of their values for each specific (one) stop at the intermediate station, passing-track, or separate point are given in Table 2.

Table 2. Parameters of the main logistical indicators of the efficiency of using UzTE16M3 diesel locomotives on the Marokand-Kattakurgan section, length L=61.75 km.

<table>
<thead>
<tr>
<th>Traction calculation option</th>
<th>Initial data</th>
<th>Kinematic parameters of freight train movement</th>
<th>Energy parameters of efficiency of use - quantitative and cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mass of composition, Q,t</td>
<td>travel speed, Vt, km/h.</td>
<td>Train travel time, min / stop</td>
</tr>
<tr>
<td></td>
<td>the number of axes in the composition of m, axes</td>
<td>total, ∆t.</td>
<td>in trust mode, ∆t.</td>
</tr>
<tr>
<td>1</td>
<td>2500</td>
<td>200</td>
<td>-2.683</td>
</tr>
<tr>
<td>2</td>
<td>3000</td>
<td>200</td>
<td>-2.683</td>
</tr>
<tr>
<td>3</td>
<td>3500</td>
<td>200</td>
<td>-2.683</td>
</tr>
<tr>
<td>Average values</td>
<td></td>
<td></td>
<td>-3.104</td>
</tr>
<tr>
<td>Values of utilization efficiency parameters for one stop of a freight train</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3000</td>
<td>200</td>
<td>0.865</td>
</tr>
<tr>
<td>Average values</td>
<td></td>
<td></td>
<td>0.871</td>
</tr>
<tr>
<td>The rate of change in the values of the parameters of efficiency of the use, the studied diesel locomotives</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3000</td>
<td>200</td>
<td>0.865</td>
</tr>
<tr>
<td>Average values</td>
<td></td>
<td></td>
<td>0.871</td>
</tr>
</tbody>
</table>

Here, we also indicate the rate of change (increase or decrease) of these values within the range of variation by the value of ∆Q=500 tons of train weight (from Q1=2500 tons to Q3=3500 tons) of a freight train on the studied, high-speed railway section Marokand-Kattakurgan of Samarkand-Navoi -Bukhara in quantitative and cost terms. In the above table, the calculated average values are arithmetic mean values.

In Table 2 the negative sign (minus) predetermines only a decrease (reduction) of the technical speed of a freight train in the process of increasing the weight of the train and no more, that is, this sign characterizes only a decrease in the value of the main indicator of the mentioned transport work and does not affect the absolute values of the technical speed.

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Fig. 1 and Fig. 2 show the dynamics of parameters of the main logistical indicators of efficiency of three-section main (train) freight locomotives UzTE16M3 on a given high-speed section Marokand -Kattakurgan of Samarkand-Navoi-Bukhara railway direction of JSC "Uzbekiston temir yullari" depending on the change in the weight of freight trains.
It should be said that the values of the above-mentioned logistical indicators were determined for one stop of a freight train, and for a more "visual" image of the nature of changes in the specific consumption of diesel fuel and cash costs in Fig. 2, their values were increased tenfold.

The diagram of the rate of change (increasing or decreasing) of the values of logistic indicators of efficiency of the UzTE16M3 diesel locomotives under study on the Marokand-Kattakurgan section in the range of differentiation (variation) for the value of ΔQ=500 t of the train mass (from Q₁=2500 t to Q₃=3500 t) of freight trains is shown in Fig. 3.

**Fig. 1.** Dynamics of logistic indicators of freight train movement on the high-speed Marokand-Kattakurgan section: ΔVₜ-technical speed; train travel time-total Δt, in traction mode Δtₜ, in no-load mode, braking mode Δtₓₓₜ.

**Fig. 2.** Dynamics of logistic indicators of energy efficiency of UzTE16M3 diesel locomotives on Marokand-Kattakurgan high-speed section: diesel fuel consumption-per trip ΔE, full Δe and conditional Δeu; cash costs-total ΔCet and reduced Δcet.

Fig. The following symbols are used: ΔVₜ-technical speed; travel time-total Δt, in traction mode Δtₜ and idle mode, braking mode Δtₓₓₜ, and Eₑₑₑ-quantitative and cost parameters of energy efficiency of the three-section main (train) freight locomotives.
Fig. 3. Rate of change in the logistical parameters of the efficiency of using UzTE16M3 diesel locomotives on the high-speed Marokand-Kattakurgan section.

The results of the analysis of the data in Table 2 and the diagram of the rate of increase-decrease of the logistical indicators of the efficiency of transportation (use) of UzTE16M3 diesel locomotives on the Marokand-Kattakurgan section allow us to state the following.

1. An increase in the weight of a freight train indicates:
   - the rate of change in the above parameter values is the same for all quantitative and cost energy efficiency indicators of the diesel traction locomotives under study and does not depend on their type or type, taking into account the increase in the range from 1.324 to 1.330 units;
   - when the technical speed \( V_t \) of the freight train movement decreases, there is a change in the rate of decline from 0.889 (Q1=2500 tons) to 0.859 (Q3=3500 tons) units;
   - the average values of the rate of increase in the running time of freight trains for different modes of operation of the power energy equipment of the studied diesel locomotives range from 1.365 (traction mode) units to 1.075 (idling and braking mode) units, and for the total travel time of the section, they are 1.154 units.

2. Reducing the weight of the freight train provides:
   - the same (constant) values of the rate of increase of the mentioned values of parameters for all types (types) of quantitative and cost energy indicators of efficiency of the studied diesel locomotives, as well as for the case of increasing the weight of the freight train, with a reduction interval of 1.339 units;
   - increase in the technical speed \( V_t \) of the freight train movement with the rate of increase, the value of which ranges from 0.859 (Q3=3500 tons) to 0.889 (Q1=2500 tons) units;
   - reduction in the rate of change in the running time of freight trains in the idling mode, braking, and total time of the train along the studied section, except for the traction mode, where the increase in the said rate of change is approximately 0.37 percent for Q1=2,500 tons and 1.55 percent for Q2 =3,000 tons.

In addition, for one-stop of a freight train at an intermediate station, passing track, or split point we have the following data:

- The value of the total and specific consumption of diesel fuel is, respectively, 36.42 kg and 2.36 kg/104tkm gross (Q1=2500 tons), 39.92 kg and 2.15 kg/104tkm gross (Q2=3000 tons) and 41.19 kg and 1.91 kg/104tkm gross (Q3=3500 tons);
- The rate of increase (decrease) of the mentioned diesel fuel consumption for every consecutive increase of the train mass by the fixed value \( \Delta Q=500 \) t changes approximately 1.096 (0.911) times - from Q1=2500 t to Q2=3000 t and 1.032 (0.888) times-from Q2=3000 t to Q3=3500 t.
- the average value of the total (total) and specific consumption of diesel fuel for traction of trains, accounting for one kilometer of railroad track is, respectively, approximately 2.04 kg/km and 0.130 kg/10^4 t km gross: km (Q1=2500 t); 2.14 kg/km and 0.116 kg/10^4 t km gross: km (Q2=3000 t) and 2.30 kg/km and 0.106 kg/10^4 t km gross: km (Q3=3500 t).
- The average value of reduced monetary costs (expenses) for traction of trains per one kilometer of railroad track is approximately 3.605 thousand cfm/km (Q1=2500 t); 3.796 thousand cfm/km (Q2 = 3000 t) and 4.076 thousand cfm/km (Q3=3500 t).

The results obtained by the authors showed sufficiently high convergence and agree well with the research data [1-2,17-and others], so they can be implemented in the analysis and assessment of fuel and energy efficiency of diesel traction locomotives on the hilly mountain, high-speed sections of the Uzbek railroads.

4 Conclusion

Significant modernization of the diesel generator units and the converter part, as well as the control system of the UzTE16M3 diesel locomotives under study, as compared to diesel traction locomotives of the 3TE10M series, has a positive effect on the traction and energy performance of the diesel locomotives under study. The research results will help to adjust the existing mode maps of train driving on the hilly-mountain, and high-speed railroad sections, the use of which will reduce the consumption of diesel fuel for traction of trains, taking into account an increase in their speed.

Obtained by the author’s logistic kinematic parameters of freight trains and indicators of energy efficiency of the studied locomotives UzTE16M3 series with the account of regression equations to determine their values will develop systematic measures and identify further ways to the economical use of natural diesel fuel for traction trains for linear enterprises locomotive complex of the Uzbek railroad.

In addition, the results of research obtained by the authors for three-section mainline (train) freight locomotives of UzTE16M3 series, which are quite successfully operated on a given, hilly-mountain, high-speed railway section Marokand-Kattakurgan, can be used in the practice of specialists of the operation shop of locomotive depot Bukhara JSC "Ўзбекистон темир yullari".

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