To the effectiveness of using of UzTE16M3 diesel locomotives on a hilly section of railroad

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Abstract. A program algorithm and a method for producing (performing) traction calculations are proposed, based on geometric constructions of changes in the speed and time of train movement along the track, relying on the specific resultant forces of the train in the travel track of rolling stock. Calculations of the kinematic parameters of the movement of a freight train on a virtual hilly section of the railway were carried out using a graphic-analytical method when moving with stops and without stops at the intermediate and final stations. The values of the energy efficiency indicators of UzTE16M3 diesel locomotives when driving a freight train with a minimum train weight in quantitative and monetary terms are substantiated. The numerical results of the research are obtained in the form of tabular data, which specialists of the locomotive complex can use when analyzing and assessing the efficiency of the transportation work of UzTE16M3 diesel locomotives under real operating conditions. Key words: Study, result, freight train, diesel locomotive, railway, parameter, siding, path, station, time, speed, hilly, virtual.

1 Introduction

Today, the total volume of railway transportation of goods by mainline diesel locomotives of the operated locomotive fleet of «Uzbekistan Temir Yollari» JSC over the past five years, in terms of the volume of their transportation work, despite its decrease by approximately 7.16 percent per year, is 40.824 million gross ton-kilometers or 26.91 percent of total cargo turnover.

The dynamics and nature of changes in the total (total) freight turnover in million gross ton-kilometers of different views (types) of locomotive traction are shown in fig. 1 [1], the analysis of the data of which determines the priority development of diesel traction, which will be directly related not only to the organization of repair production of diesel locomotives of high high-quality, but also to the replenishment of the locomotive fleet of «Uzbekistan Temir Yollari» JSC with modern diesel locomotives of a new generation.

The above predetermines the relevance of conducting such theoretical studies, the results of which will be aimed at justifying the effectiveness of the use of diesel locomotives in real conditions of organizing freight railway traffic on sections of the Uzbek railways of varying difficulty (complexity), including hilly ones, taking into account the

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subsequent development of practical recommendations and complex measures for specialists of the locomotive depots operation workshop.

**Fig.1.** Diagram of distribution of cargo turnover along railways sections of «Uzbekistan Temir Yollari» JSC. Source: «Compiled by the author».

### 2 Objects and methods of research

Improving the quality of repair and the efficiency of using locomotives under operating conditions can be achieved through an integrated approach to the development and implementation of organizational, technical, design and technological measures (recommendations) into the work practice of specialists of the locomotive complex of the railway network including of Uzbek ones.

Currently, along with the acquisition of modern diesel locomotives from Russia and the People's Republic of China (PRC), one of the ways to replenish the locomotive fleet of «Uzbekistan Temir Yollari» JSC with new generation diesel locomotives is the “deep” modernization of diesel locomotives of the TE10M series in various sectional designs, which consists of replacing the previous power plant with a new one [2] - a 1A-9DG diesel generator with a 1A-5D49 diesel engine, as well as using a unified locomotive automation system (USTA-75-02), of an complex locomotive safety device (CLUB-U) and of a unified control panel driving modes the train.

The specified diesel locomotive refers to a land-based wheeled vehicle with a power energy plant [3] - this is diesel 1A-5D49 of the third version, which is characterized by high efficiency with specific fuel consumption at rated power mode (2206 kW) equal to 208 g/kW-h and hourly fuel consumption of idle mode - 14 kg/h.

An analysis of scientific research by domestic scientists [4-11] and scientists from far abroad [12-24], aimed at studying the efficiency of various types of locomotives, their systems, units and apparatus in the conditions of operational activity of railways and of railway transportation of goods the organization, indicates that no the a sufficient degree of study of issues related to the justification of the kinematic parameters of the movement of freight trains and the parameters of the energy efficiency of locomotives on virtual and real sections of railways of varying complexity, including of Uzbek ones.

In this regard, the above is the goal of this study and for its implementation the author
uses the enlarged program algorithm he developed [25], the essence of which is outlined below, and the methodology [26] for locomotives of diesel locomotive traction (diesel traction), based on geometric constructions of speed changes and the time of movement of the train along the track, taking into account the specific resultant forces of the train along the route movement of the rolling stock, as well as the accepted object and subject of research, and the straightened profile tracks [27] of the virtual hilly section of the railway.

The object of the study is freight trains that have a minimum mass of the train \( Q = 2500 \) tons and fifty four-axle cars \( m = 200 \) axles in the train, three-section mainline (train) freight diesel locomotives of the \( UzTE16M3 \) series and a virtual hilly section with the second type of railway track profile difficulty.

The subject of the study is the speed and time of movement of a freight train with a minimum mass of the train with a constant number of axles in it, as well as the parameters of the main indicators of energy efficiency of the studied \( UzTE16M3 \) diesel locomotives, taking into account quantitative and monetary costs on a given virtual hilly section of the railway.

The accepted straightened track profile of a virtual hilly section of a high-speed railway and the speed of freight trains along the hauls of the section, and along it in general, are given in the study [28]. Traction and energy characteristics, technical parameters taking into account the design features of the \( UzTE16M3 \) diesel locomotive under study are indicated in [3].

According to the theory of locomotive traction, the movement of a train on a railway section is described by the well-known [29] differential equation of train motion \( \frac{dv}{dt} = \xi u, \) km/h\(^2\), which relates the train acceleration \( \frac{dv}{dt} \) with the specific resultant force \( u, \) N/kN.

Dividing both parts by the train speed \( V \), taking into account \( v = \frac{v}{dS} \), we get

\[
\frac{dv}{v dt} = \frac{dv}{dS} = \frac{\xi u}{v} = \frac{\xi f(V)}{v} = f(V)
\]

where \( u = \varphi(V) \) – specific resultant force of the train, N/kN.

Based on equation (1), all problems are solved and including the problem of this article, related to calculations of the transportation work of locomotives on railway sections, and therefore, the accuracy of solving this equation largely determines the reliability of the values of indicators of operational, energy and economic efficiency of the use of locomotives under operating conditions.

With a known rise (slope) \( i_k, \) (‰), the value of the specific resultant force in mode traction (power stroke) will be

\[
u = f_k(V) - w_0(V) + i_k
\]

in idling mode she will be equal to

\[
u = -w_0(V) + i_k
\]

and when braking mode it will be correspond

\[
u = -[w_0(V) + i_k + b_t(V)]
\]

where \( f_k(V) = \frac{f_k(V)}{P + Q}, \) dependence of the specific tangential traction force of a locomotive on the speed of movement for a particular position of the locomotive driver’s controller, for a given train weight \( (P + Q) \), kN.
$w_0(V)$ – dependence of the specific main resistance to the movement of the train on its speed movement. It is found taking into account the main resistance to movement of the locomotive $w'_0(V)$ and the composition $w''_0(V)$, which are calculated from empirical dependencies [29].

Thus

$$w_0(V) = \frac{p_0 w'_0(V) + Q w''_0(V)}{p_0 + Q} \cdot \frac{H}{\mu H}, \frac{H}{\mu H}$$  
(5)

$b_s(V)$ – dependence of the specific braking force on the train speed movement for existing braking devices.

In this article, the author uses a graphical-analytical method for solving the differential equation of train motion (1), which is based on the geometric mutual relationship between the specific resultant (accelerating or decelerating) forces in each interval of movement speeds not exceeding the value $\Delta V = 10 \text{ km/h}$, of travel time $t$ and distance traveled $S$.

Moreover, the basic component of all varieties of this solution method is the graphical integration of the differential equation of train motion using the finite increment method. Only, for this, the author does not use calculations (analytical or numerical calculations), but geometric constructions of changes in the speed and time of movement of the train along the track, the essence of which boils down to the following.

The initial data are graphs of the specific accelerating force $f_y(V) = f(V) - w_b(V) \pm i(S)$ and the specific main resistance to train movement $w_{bm}(V)$ in idle mode (coasting). The traction calculation consists in the fact that the permissible value of the train speed in a given section is divided into successive fairly small intervals $\Delta V \leq 10 \text{ km/h}$, at each of which the average value of the speed is found in the form $V_{cp} = \frac{V_1 + V_2}{2}$. Then, according to the graph of specific accelerating forces $f_y(V_{cp})$, for a given value $V_{cp}$, the average value $f_y(V_{cp})$ is determined, and from it the corresponding time interval $\Delta t = \Delta V/\xi f_y(V_{cp})$ and the path interval $\Delta S$ are calculated. As the calculation is carried out, a table of the obtained values is compiled, on the basis of which curves of the speed $V(S)$ and time $t(S)$ of the train's movement are drawn under the accepted modes of its movement.

To implement the above, an enlarged algorithm for the traction calculation program has been developed, the block diagram of which is shown in fig. 2.

The specified program contains 11 blocks and works as follows. In block 1, the initial conditions are set, as a rule, these are the initial coordinate of the track and the speed movement of the train. In block 2, comparisons are made between the current coordinates of the train and the coordinates of the track profile. At the beginning of the calculation, the coordinate of the first element of the path profile is selected. If the current coordinate of the train is greater than the coordinate of the current track profile, then control is transferred to block 3, where the coordinate counter of the track profile element is changed and the transition to the next track profile element is made.

Next, control returns to block 2 for re-checking. If the current coordinate of the train is within the boundaries of the current track profile, then control is transferred to block 4, in which, in accordance with the current speed movement and coordinate of the train, are determined the resistance forces to the movement. In block 5, the possibility of moving to the next, different regulation position (locomotive driver controller) is determined and information about this is displayed on the screen. In block 6, the position of the locomotive driver's controller is selected. Here, it is possible to remain at the previous specified regulation position, or move to a higher or lower position of the locomotive driver’s controller, as well as switch to the idle (of coasting) mode or braking mode.
In block 7, the selected position of the locomotive driver’s controller is checked against what is possible at this calculation step. If the selected position is outside the permissible values, then control is transferred to block 8 and after that control is again transferred to block 6. If the selected control position falls within the permissible range, then block 9 calculates the accelerating and decelerating (specific resultant) forces of the train.

In block 10, the equation of train motion is solved, as a result of which the increment in speed and time of movement is determined according to a given (accepted) coordinate increment. In block 11, the current coordinate is compared with the final one. If the current coordinate is less than the final one, then control returns to block 2 or otherwise the calculation ends.

It should be noted that the purpose of block 3 is to use the built-in «Data base Offset» function, which allows you to read the contents of a cell shifted relative to the specified one by a certain number of positions. The sequential shift algorithm in the database, which would determine the necessary shift in order to extract the necessary information, is implemented in the form of a block diagram presented in fig. 3.
Thus, based on the above, in order to achieve the stated goal of the research, the author developed a mathematical model for driving a freight train with the studied diesel locomotive UzTE16M3 series, calculated a table and constructed a diagram of the specific resultant forces of the train, and graphically was be constructed the trajectory of the train (travel speed and train travel time curves) on a given virtual hilly section of the railway.

3 Results and their discussion

In table 1 shows the numerical values of the specific accelerating and slowing down (resultant) forces of a freight train, the minimum mass and number of axles of which for various modes of train operation are, respectively, \( Q = 2500 \) t and \( m = 200 \) axles.

Table 1. Specific accelerating and slowing down (resultant) forces of a freight train, \( Q = 2500 \) t, \( m = 200 \) axles, UzTE16M3 diesel locomotives

<table>
<thead>
<tr>
<th>( V ) (km/h)</th>
<th>( F_a ) (N)</th>
<th>( w_0 ) (kN)</th>
<th>( w_n ) (kN)</th>
<th>( w_0 ) (kN)</th>
<th>( f_a - w_0 ) (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>0</td>
<td>1360000</td>
<td>1,90</td>
<td>0,94</td>
<td>1,04</td>
<td>46,50</td>
</tr>
<tr>
<td>10</td>
<td>1168000</td>
<td>2,03</td>
<td>1,04</td>
<td>1,08</td>
<td>39,68</td>
</tr>
<tr>
<td>13</td>
<td>1125000</td>
<td>2,08</td>
<td>1,08</td>
<td>1,14</td>
<td>38,13</td>
</tr>
<tr>
<td>20</td>
<td>839000</td>
<td>2,22</td>
<td>1,18</td>
<td>1,29</td>
<td>28,02</td>
</tr>
<tr>
<td>30</td>
<td>600000</td>
<td>2,47</td>
<td>1,36</td>
<td>1,47</td>
<td>19,47</td>
</tr>
<tr>
<td>40</td>
<td>470000</td>
<td>2,78</td>
<td>1,58</td>
<td>1,70</td>
<td>14,69</td>
</tr>
<tr>
<td>50</td>
<td>375000</td>
<td>3,15</td>
<td>1,84</td>
<td>1,79</td>
<td>11,02</td>
</tr>
<tr>
<td>60</td>
<td>312000</td>
<td>3,58</td>
<td>2,14</td>
<td>1,98</td>
<td>8,57</td>
</tr>
<tr>
<td>70</td>
<td>273000</td>
<td>4,07</td>
<td>2,48</td>
<td>2,17</td>
<td>6,84</td>
</tr>
<tr>
<td>80</td>
<td>235000</td>
<td>4,62</td>
<td>2,86</td>
<td>2,29</td>
<td>5,11</td>
</tr>
<tr>
<td>90</td>
<td>214000</td>
<td>5,23</td>
<td>3,28</td>
<td>2,64</td>
<td>3,93</td>
</tr>
<tr>
<td>100</td>
<td>194000</td>
<td>5,90</td>
<td>3,74</td>
<td>3,05</td>
<td>2,74</td>
</tr>
</tbody>
</table>
V I dling and braking modes

<table>
<thead>
<tr>
<th>$V$ (km/h)</th>
<th>$w_x$ (N/kN)</th>
<th>$\varphi_x$</th>
<th>$b_x$ (N/kN)</th>
<th>$w_\text{tot}$ (N/kN)</th>
<th>$w_\text{tot}+0.5b_x$ (N/kN)</th>
<th>$w_\text{tot}+b_x$ (N/kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.40</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>10</td>
<td>2.54</td>
<td>1,198</td>
<td>65.34</td>
<td>1.25</td>
<td>33.92</td>
<td>66.59</td>
</tr>
<tr>
<td>13</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>20</td>
<td>2.76</td>
<td>0.162</td>
<td>53.46</td>
<td>1.40</td>
<td>28.13</td>
<td>54.86</td>
</tr>
<tr>
<td>30</td>
<td>3.05</td>
<td>0.140</td>
<td>46.20</td>
<td>1.60</td>
<td>24.70</td>
<td>47.80</td>
</tr>
<tr>
<td>40</td>
<td>3.40</td>
<td>0.126</td>
<td>41.58</td>
<td>1.84</td>
<td>22.63</td>
<td>43.42</td>
</tr>
<tr>
<td>50</td>
<td>3.83</td>
<td>0.116</td>
<td>38.28</td>
<td>2.12</td>
<td>21.26</td>
<td>40.40</td>
</tr>
<tr>
<td>60</td>
<td>4.32</td>
<td>0.108</td>
<td>35.64</td>
<td>2.45</td>
<td>20.27</td>
<td>38.09</td>
</tr>
<tr>
<td>70</td>
<td>4.89</td>
<td>0.102</td>
<td>33.66</td>
<td>2.82</td>
<td>19.65</td>
<td>36.48</td>
</tr>
<tr>
<td>80</td>
<td>5.52</td>
<td>0.097</td>
<td>32.01</td>
<td>3.24</td>
<td>19.24</td>
<td>35.25</td>
</tr>
<tr>
<td>90</td>
<td>6.23</td>
<td>0.093</td>
<td>30.69</td>
<td>3.70</td>
<td>19.04</td>
<td>34.39</td>
</tr>
<tr>
<td>100</td>
<td>7.00</td>
<td>0.090</td>
<td>29.70</td>
<td>4.20</td>
<td>19.01</td>
<td>33.90</td>
</tr>
</tbody>
</table>

Source: «Compiled by the author».

Graphic construction of the diagram of the mentioned resultant forces of the train for the studied UzTE16M3 diesel locomotives was carried out according to the data in table 1 on a millimeter tablet according to the recommended [29] graphic construction scales.

In table 2 and table 3 shows the running times of freight trains with a minimum mass of the train along the stages of a virtual hilly section of the railway, taking into account the time for deceleration - acceleration when implementing railway transportation of cargo of different content and of type. Here, the averaged values of the indicated parameters when a freight train moves without stops and with stops at the intermediate and final stations of a virtual hilly section of the railway are determined as the arithmetic mean value.

Table 2. Travel time of a freight train by hauls without stops, and at the intermediate station on for deceleration – acceleration

<table>
<thead>
<tr>
<th>No. in order</th>
<th>Stations</th>
<th>Distance, km</th>
<th>Travel time, min</th>
<th>Time on deceleration / on acceleration, min</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Station D</td>
<td>-</td>
<td>-</td>
<td>- / 2.0</td>
</tr>
<tr>
<td>2</td>
<td>Station E</td>
<td>22.40</td>
<td>17.30</td>
<td>1.55 / 1.85</td>
</tr>
<tr>
<td>3</td>
<td>Station F</td>
<td>23.50</td>
<td>14.70</td>
<td>1.70 / -</td>
</tr>
<tr>
<td>4</td>
<td>Section D – F</td>
<td>45.90</td>
<td>32.00</td>
<td>1.62 / 1.92</td>
</tr>
</tbody>
</table>

Source: «Compiled by the author».

Table 3. Speed and travel time of a freight train by hauls of virtual hilly section of the railway, UzTE16M3 diesel locomotives

<table>
<thead>
<tr>
<th>speed movements $V$, km/h</th>
<th>on the haul, min</th>
<th>in mode, min</th>
<th>of traction</th>
<th>of idle and braking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haul $D – E$</td>
<td>77,68/71,11</td>
<td>17,30/18,90</td>
<td>15,40/14,80</td>
<td>1,90/4,10</td>
</tr>
<tr>
<td>Haul $E – F$</td>
<td>95,91/77,47</td>
<td>14,70/18,20</td>
<td>6,80/8,90</td>
<td>7,90/9,30</td>
</tr>
<tr>
<td>Section $D – F$</td>
<td>86,06/74,23</td>
<td>32,00/37,10</td>
<td>22,20/23,70</td>
<td>9,80/13,40</td>
</tr>
<tr>
<td>Average values for two types of movement</td>
<td>80,14</td>
<td>34,55</td>
<td>22,95</td>
<td>11,60</td>
</tr>
</tbody>
</table>

Source: «Compiled by the author».
In Table 4 shows the values of the main fuel and energy indicators of the efficiency of using traction diesel rolling stock (locomotives of diesel traction), which represent the total (total) and specific consumption of natural diesel fuel in quantitative and monetary terms. The specified diesel fuel is consumed by the studied freight diesel locomotives UzTE16M3 series when they move non-stop and with stops along the route of a freight train with a minimum mass of the train and a constant number of axles in the train along the hauls of a virtual hilly section of the railway.

**Table 4.** Parameters of energy efficiency indicators of UzTE16M3 diesel locomotives when moving a freight train with a minimum train weight along the stages of a virtual hilly section of the railway

<table>
<thead>
<tr>
<th>At the intermediate and final arrival station</th>
</tr>
</thead>
<tbody>
<tr>
<td>without stops</td>
</tr>
<tr>
<td>full $E$, kg</td>
</tr>
<tr>
<td>Haul $D - E$</td>
</tr>
<tr>
<td>350,12</td>
</tr>
<tr>
<td>Haul $E - F$</td>
</tr>
<tr>
<td>159,47</td>
</tr>
<tr>
<td>Section $D - F$</td>
</tr>
<tr>
<td>509,59</td>
</tr>
</tbody>
</table>

Source: «Compiled by the author».

Comparison of data from Table 3 and Table 4 and the analysis of the trajectories of freight trains with a minimum mass of the train on a virtual hilly section of the railway with the second type of track profile difficulty shows that the movement of the studied freight trains, organized without stops at an intermediate station in relation to similar movement with stops at it, contributes to:
- a decrease in the total time of the train by 5.10 minutes with an increase in the technical speed of movement by 11.83 km/h;
- the values of the shares of movement in modes traction at 69.37 percent, and idling and braking at 30.63 percent;
- the calculated average value of the total (full) time for acceleration - deceleration is 3.54 minutes;
- a decrease in the total (full) and specific consumption of full-scale diesel fuel by an average of 6.68 percent;
- a reduction in the total (full) and specific consumption of full-scale diesel fuel in monetary terms by an average of 6.68 percent.

According to the table 4 and by the constructed trajectories of the studied freight train on a virtual hilly section of the railway with stops at an intermediate station were obtained, the following numerical values of the main parameters of energy efficiency indicators work for the of three-section mainline (train) freight diesel locomotives UzTE16M3series, namely:
- consumption of full-scale diesel fuel for one stop at an intermediate station is 36.46 kg, and for one acceleration - deceleration - 43.49 kg;
- specific consumption of full-scale diesel fuel for one stop at an intermediate station is 3.18 kg / 10^4 t km gross, and for one acceleration - deceleration - approximately 1.59 kg / 10^4 t km gross;
- consumption of specific cash costs for one stop at an intermediate station is 1406.3 soum / km, and for one acceleration - deceleration - 703.15 soum / km;
- the average value of the consumption of specific monetary resources for two types of traffic is 20359.05 soum / km.

The results of this research, obtained by the author, as having shown a fairly high convergence and consistency with research data [2, 3, 26-28, 30 and others], can be recommended for the practice of specialists in the locomotive complex of railways, including Uzbek ones, in the analysis, assessment and justification of traction – energy parameters of the transportation work of locomotives diesel traction on real, hilly sections of railways.

4 Conclusion

Thus, summing up the above, we can state the following results of these studies:

1. A program algorithm and methodology for performing traction calculations for locomotives diesel traction have been developed, thanks to which the trajectories of a freight train with a minimum mass and a constant number of axles in the train were obtained, implemented by UzTE16M3 diesel locomotives on a hilly section of the railway.
2. The kinematic parameters of the movement of a freight train of this category during its with stops at the intermediate and final stations of a given hilly section of the railway are substantiated.
3. The kinematic parameters of the movement of a freight train with a minimum mass of the train and the main parameters of the energy efficiency indicators of three-section mainline (train) freight diesel locomotives of the UzTE16M3 series are substantiated in quantitative and monetary terms on a hilly section of the railway.
4. The dynamics of changes in the speed and travel time of the studied freight train, as well as the consumption of natural diesel fuel by the studied diesel locomotives of the UzTE16M3 series, were obtained, depending on the type of organization of freight movement on a hilly section of the railway.

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