To the efficiency of locomotives of electric tractions on a hilly of section of the railway track

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Abstract. The article provides a rationale for the kinematic parameters of the movement of freight trains with masses different and the energy efficiency parameters of 3VL80S electric locomotives on a virtual hilly section of the railway. In order to implement this justification, a method of graphically integrating the differential equation of train motion is used, which is the basis of the algorithm for performing traction calculations for the movement of the freight trains under study without stoppings at an intermediate station. Kinematic parameters of the movement of freight trains and energy efficiency indicators of 3VL80S electric locomotives are obtained in the form of tabular data and regression equations according to their definition on railway sections with the second type of track profile, which can be used in predicting and normalizing the consumption of electrical energy for traction of trains. The research results are recommended for implementation into work by specialists of the locomotive depots operation workshop of «Uzbekistan Temir Yollari» JSC. Key words: Study, efficiency, electric traction, result, freight train, electric locomotive, without stops, railway, parameter, siding, path, station, time, speed, hilly, virtual.

1 Introduction

Recently, a noticeable increase in the total length of electrified sections of the Uzbek railways and the replenishment of the locomotive fleet of «Uzbekistan Railways» JSC with new electric locomotives of Chinese and Russian production determine the priority direction in the development of electric traction.

The above undoubtedly contributes to increasing the efficiency of transportation work of the electric locomotive part of the locomotive fleet of the railway industry of Uzbekistan. Despite this, the demand for electric locomotives of the VL80S series in three-section design remains quite high. Indeed [1], now 3VL80S electric locomotives carry out about fifty-nine percent of the total actual volume of railway cargo transportation on sections of the Uzbek railways of varying degrees of complexity (difficulty).
Therefore, research on the effectiveness of using these electric locomotives under operating conditions on real and virtual sections of railways of varying degrees of complexity is timely and relevant.

2 Objects and methods of research

It should be said that many scientists from different countries, first of all, give preference to research aimed at increasing the efficiency of using traction rolling stock of railways, including electric ones, in various conditions of railway transportation of goods and passengers.

The analysis of a fairly large number of research works by foreign scientists, some of which are presented in this article [2-20], shows that all of them are devoted to research on improving the quality of repairs and the repair component of the production of the locomotive complex of railways, as well as of operational reliability on the way following ordinary, speed and high-speed electric rolling stock.

These studies and their results, having a certain scientific interest and high practical significance, are completely divorced from the problematic issues of the railway industry of Uzbekistan related to the justification of the parameters of the main indicators of transportation work and the efficiency of traction electric rolling stock in real conditions of organizing freight transportation on of varying of complexity Uzbek railways.

These studies continue the work [21-23] for traction electric rolling stock - 3VL80S electric locomotives, with the help of which rail freight transportation is organized on a virtual hilly section of the railway. The purpose of the study is to substantiate the efficiency indicators of using 3VL80S electric locomotives under operating conditions, taking into account the kinematic parameters of the movement of freight trains and to study the influence of real conditions for organizing freight rail transportation on these indicators when moving without stoppings at intermediate stations.

Here, as the main indicators of the efficiency of 3VL80S electric locomotives in freight transportation conditions, the author of this article takes the speed movement and running time of the train on the section under study in different operating modes of the force energy plant, as well the energy parameters of 3VL80S electric locomotives in terms of the amount of electrical energy they expended on traction of trains in quantitative and monetary terms.

To realize the stated goal of research and select a trajectory in at unsteady train movement mode, the author of this article uses an algorithm and methodology for performing traction calculation by graphically integrating the differential equation of train motion, taking into account the initial data about of freight electric locomotives of the 3VL80S series, about the composition of the freight train and a virtual hilly section of the railway, as well as the object and subject of research.

Solving the problem for an unsteady mode of train movement allows us to calculate the acceleration and braking modes of the train, the speed and time of movement him along various elements of the track profile, taking into account the possibility of using kinetic energy to overcome “inertial” rises, the steepness of which is greater than the calculated rise.

The initial data for traction calculation are: straightened track profile; the maximum permissible speed and its restrictions on the stretch; railway car type; registration length of the railway car; number of axles and carrying capacity of the railway car; wagon load factor; length of receiving and departure tracks; type, series and reference length of the locomotive; design force traction and weight of the locomotive; design speed of the locomotive.
The differential equation of train motion is a mathematical expression that relates the kinematic parameters of train motion (speed and travel time of the train) with the magnitude of the forces acting on it.

The equation of train motion can be written as a system [24, 25]

\[
\frac{ds}{dt} = v,
\]

\[
\frac{dv}{dt} = \xi \left[ \frac{F}{P+Q} - \frac{B}{P+Q} - w_0 - w_d \right],
\]

where \( P \) is the mass of the locomotive or electric train cars, \( Q \) is the mass of the train or the mass of passengers of the electric train, \( w_0 \) is the specific main resistance to movement, \( w_d \) is the specific additional resistance to movement, \( \xi = \frac{\varepsilon}{\gamma} \), \( f = \frac{F}{P+Q} \), and \( b = \frac{B}{P+Q} \).

In mode traction \( F > 0, B = 0 \); in coasting mode, when the traction motors are turned off, \( F = 0, B = 0 \); in braking mode \( F = 0, B > 0 \).

Let us write equations (3) in the following form

\[
\frac{dv}{ds} = \frac{\xi}{v} \left[ \frac{F}{P+Q} - \frac{B}{P+Q} - w_0 - w_d \right],
\]

\[
\xi = \frac{\varepsilon}{\gamma} \quad f = \frac{F}{P+Q} \quad b = \frac{B}{P+Q}.
\]

Then, the approximate solution for the movement time will be

\[
\Delta t = \frac{\Delta V}{\xi f - w - b}.
\]
\[
V_j = V_{j-1} + \Delta V \\
S_j = S_{j-1} + \sqrt{\xi f - w - b}
\]

The object of the study is freight trains with different weights and a constant number of train axles, three-section mainline (train) freight electric locomotives of the 3 VL 80 S series with systems for providing stepwise contactor voltage regulation of collector traction electric motors of sequential excitation, of rheostatic braking and the ability to simultaneously control three sections of the same type, as well as a straightened profile tracks of a virtual hilly section of the railway.

The subject of the study is the main kinematic parameters of the movement of freight trains when moving without stopping at an intermediate station and the energy efficiency indicators of the studied 3 VL 80 S electric locomotives in quantitative and monetary terms on the accepted (given) virtual section of the railway.

The characteristic of the studied virtual hilly section of the railway are given in table 1.

<table>
<thead>
<tr>
<th>№ element</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
</tr>
</thead>
<tbody>
<tr>
<td>i, ‰</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>S, m</td>
<td>1700</td>
<td>4800</td>
<td>2800</td>
<td>7000</td>
<td>2100</td>
<td>1500</td>
<td>7200</td>
<td>2500</td>
<td>2500</td>
<td>1600</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: «Compiled by the author».
3 Results and their discussion

Traction calculations were performed for three variants of driving freight trains with different masses of trains and its successive change by $\Delta Q = 500$ tons on a virtual hilly section of the railway, and the number of axles in the trains was assumed to be constant and equal $m = 200$ axles. The movement of these freight trains in all cases of rail freight transportation was organized without stoppings at the intermediate station.

The numerical values of the kinematic parameters of the movement of freight trains for each stretch and virtual hilly section of the railway, in general, for various operating modes of the power energy systems of $3 VL 80 S$ electric locomotives and the specified conditions for the implementation by of railway transportation of different types and structure of cargo are given in table 2.

<table>
<thead>
<tr>
<th>No. in order</th>
<th>mass of composition $Q$, t</th>
<th>Freight train movement without stops speed $V$, km/h on the haul, min</th>
<th>traction of idle and braking $H$, min</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2500</td>
<td>86.43</td>
<td>15.55</td>
</tr>
<tr>
<td>2</td>
<td>3000</td>
<td>84.52</td>
<td>15.90</td>
</tr>
<tr>
<td>3</td>
<td>3500</td>
<td>77.68</td>
<td>17.30</td>
</tr>
</tbody>
</table>

Table 2. Distribution of freight train movement travel time across hauls of virtual hilly section of railway, $3 VL 80 S$ electric locomotive

In table 3 shows the parameters of the energy efficiency indicators of using three-section mainline (train) freight electric locomotives $3 VL 80 S$ on a virtual hilly section of the railway when moving without stops at an intermediate separate point in quantitative and monetary terms, taking into of different conditions for organizing the transportation work of the locomotives under study. Index (sign) asterisk * - cash costs (cost of electrical energy) including value added tax (VAT).
Таблица 3. Основные показатели использования электровозов 80S на виртуальном горном участке

<table>
<thead>
<tr>
<th>Место</th>
<th>Скорость, км/ч</th>
<th>Участок</th>
<th>Электрообъем, кВт·ч</th>
<th>Участок</th>
<th>Электрообъем, кВт·ч</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>86,43</td>
<td>D-E</td>
<td>1585,42</td>
<td>86,43</td>
<td>1585,42</td>
</tr>
<tr>
<td>2</td>
<td>84,52</td>
<td>D-E</td>
<td>1843,12</td>
<td>84,52</td>
<td>1843,12</td>
</tr>
<tr>
<td>3</td>
<td>77,68</td>
<td>D-E</td>
<td>2017,97</td>
<td>77,68</td>
<td>2017,97</td>
</tr>
<tr>
<td>4</td>
<td>96,57</td>
<td>E-F</td>
<td>778,16</td>
<td>96,57</td>
<td>778,16</td>
</tr>
<tr>
<td>5</td>
<td>94,00</td>
<td>E-F</td>
<td>819,00</td>
<td>94,00</td>
<td>819,00</td>
</tr>
<tr>
<td>6</td>
<td>95,27</td>
<td>E-F</td>
<td>847,10</td>
<td>95,27</td>
<td>847,10</td>
</tr>
<tr>
<td>7</td>
<td>91,34</td>
<td>D-F</td>
<td>2363,58</td>
<td>91,34</td>
<td>2363,58</td>
</tr>
<tr>
<td>8</td>
<td>89,12</td>
<td>D-F</td>
<td>2662,12</td>
<td>89,12</td>
<td>2662,12</td>
</tr>
<tr>
<td>9</td>
<td>85,79</td>
<td>D-F</td>
<td>2865,07</td>
<td>85,79</td>
<td>2865,07</td>
</tr>
</tbody>
</table>

Источник: «Составлено автором». https://doi.org/10.1051/e3sconf/202345803025
Evaluation and analysis of the efficiency of the transportation operation of three-section mainline (train) freight electric locomotives 3VL80S series on a given, virtual, hilly section of the railway were carried out by comparing the numerical values of the above-mentioned kinematic and energy parameters with similar values for a unified (graphic) freight train.

Analysis of the research results [1, 21, 22] and the data in table 1 in relation to a unified freight train with a mass of the train \( Q_2 = 3000 \) tons and a constant number of axles \( m = 200 \) in the train shows the following.

1. The average total travel movement time of the train is 0.517 hours, an increase in the mass of the train by \( \Delta Q = 500 \) tons leads to an increase in this time by 3.88 percent, and with a decrease in the mass of the train by \( \Delta Q = 500 \) tons, the total travel time of the train decreases by 2.43 percent.

2. The technical speed of the train, with a similar change in the mass of the train, tends to decrease and increase within the same limits, and, on average, it is equal to 88.75 km/h.

3. The average train travel time for acceleration and deceleration is 0.0341 hours, an increase in the mass of the train by \( \Delta Q = 500 \) tons leads to an increase in the train travel time for acceleration and deceleration, respectively, by 6.6 percent and 4.72 percent. With a decrease in the mass of the train by \( \Delta Q = 500 \) tons, the time for deceleration and acceleration decreases, respectively, by 3.55 percent and 7.07 percent.

4. The total and specific average consumption of electrical energy for traction of trains is, respectively, 2630.26 kW·h and 19.25 W·h/t km. The total and specific average costs of electrical energy correspond, respectively, to 228937.3 soum and 5024.76 soum – excluding VAT and 274599 soum and 5982.5 soum – including VAT.

5. Reducing the mass of the train by \( \Delta Q = 500 \) t ensures a decrease in the total and an increase in specific energy consumption, respectively, by 11.21 and 6.52 percent, and an increase in the mass of the train by \( \Delta Q = 500 \) t contributes to an increase in the total energy consumption by 7.62 percent, however, the specific energy consumption decreases by 7.76 percent.

6. An increase in the mass of the train by \( \Delta Q = 500 \) tons leads to an increase in the total and specific cost by an average of 7.62 percent, and with a decrease in the mass of the train by \( \Delta Q = 500 \) tons, the total and specific cost decreases by an average of 11.21 percent.

7. An increase in the mass of the train by \( \Delta Q = 500 \) t leads to a decrease and increase in the use of traction modes, as well as idling and braking, respectively, by 1.53 percent, and with a decrease in the mass of the train by \( \Delta Q = 500 \) t there is an increase and a decrease in these indicators by 0.8 percent.

8. The running time of the train in idle and braking modes, as well as in mode traction, varies, respectively, from 0.168 hours to 0.192 hours and from 0.334 hours to 0.3243. The running time of the train in idling and braking mode increases, and in traction mode it decreases, respectively, by 0.008 hours and 0.004 hours with a decrease in the mass of the train by \( \Delta Q = 500 \) tons. When the mass of the train increases by \( \Delta Q = 500 \) t, the train running time in idling and braking modes, as well as in mode traction, increases by 0.015 hours and 0.005 hours, respectively.

Using the standard Microsoft Office Excel series program, regression equations (analytic expressions) were obtained to calculate the parameters of the main indicators of the transportation operation of 3VL80S electric locomotives on a virtual hilly section of the railway track for any \( i \)-th mass \( Q_i \) of a freight train. In formulas (1) – (10), a sufficient value of reliability of the approximation is \( R^2 = 1.0 \) (the necessary condition for reliability is \( R^2 \geq 0.8 \)), and the sign (index) asterisk * - taking into account value added tax (VAT), and value \( Q_i = 1, 2, 3 \) – is a factor (indicator) option of the traction of calculation.
\[ V_t = -0.555Q^2 - 0.555Q + 92.45 \] (1)

Total train travel time \( t_{tr} \), min

\[ t_{tr} = 0.225Q^2 - 0.075Q + 29.86 \] (2)

Train travel time in mode traction \( t_{tr} \), min

\[ t_{tr} = 0.025Q^2 + 0.175Q + 19.85 \] (3)

Train running time at idle and braking modes \( t_{id,br} \), min

\[ t_{id,br} = 0.2Q^2 - 0.1Q + 10.0 \] (4)

Total of electric energy consumption per trip \( A \), kW·h

\[ A = -47.7956Q^2 + 441.93Q + 1969.4 \] (5)

Specific of electric energy consumption per trip \( a \), W·h/t km gross

\[ a = -0.12Q^2 - 0.9Q + 21.61 \] (6)

Total cash costs \( C_e \), soum

\[ C_e = -4160.5Q^2 + 38467Q + 171420 \] (7)

Total cash costs \( C_e^* \) in view of VAT, soum

\[ C_e^* = -4990.5Q^2 + 46140Q + 205609 \] (8)

Specific cash costs \( c_e \), soum/km

\[ c_e = -35.15Q^2 + 671.55Q + 3845.7 \] (9)

Specific cash costs \( c_e^* \) in view of VAT, soum/km

\[ c_e^* = -108.7Q^2 + 1005.1Q + 4479.6 \] (10)

Analysis of the above regression equations shows that the dynamics of all the above parameters when the mass of composition of a freight train changes is described by a polynomial of the second degree.

Analysis of the results of the research shows the following:

- when organizing railway transportation of various goods, slow and accelerated types of movement, that is, movement with a changing and inconsistent speed, coexist only in cases of braking (stopping), starting and accelerating, and the uniform movement of a freight train is exclusively dominant;

- the amount of electrical energy spent on moving freight trains by electric locomotives 3VL80S series directly depends on the operating time of power energy installations (systems) under current, that is, in mode traction, a decrease in which will lead to a decrease in the mechanical work of the mentioned electric locomotives, and as a result, will ensure a reduction in consumption (consumption) of electrical energy;
- an increase in the volume of transportation work by 3VL80S electric locomotives helps to increase the efficiency of using these electric locomotives under operating conditions and does not depend on the type of cargo transported and the type of movement of freight trains.

4 Conclusion

1. The author of this article, firstly, substantiated the main kinematic parameters of the movement of freight trains and the parameters of the energy efficiency indicators of 3VL80S electric locomotives, and secondly, obtained regression equations to determine the main indicators of the transportation work of electric locomotives of the 3VL80S series on virtual and, identical to them, real hilly sections of the railway. Moreover, the organization of freight traffic is carried out without stops along the route of the rolling stock.

2. To implement the algorithm and methodology for performing traction calculations, the author uses a graphical method of integrating the differential equation of train motion, which made it possible to obtain the trajectories of freight trains on a virtual section of the railway in the form of curves of speed and time of train movement, and of a curve of the current consumed by the electric locomotive under study.

3. The research results obtained by the author are recommended for implementation into practice of the work of drivers - heat engineering instructors and specialists of the operation shop of the locomotive complex of the Uzbek railways with a hilly track profile, on which the movement of freight trains is carried out by locomotives of electric traction.

References


