

Operation of locomotives of diesel traction on hilly section of railway

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Abstract. The results of substantiation of the kinematic parameters of the logistics of freight trains and locomotives of diesel traction are presented, taking into account the stopping process at the intermediate and terminal stations of a virtual hilly section of the railway. Tabular and graphic data of the logistic kinematic parameters of the movement of the studied freight trains and locomotives of diesel traction are obtained, taking into account the organization of stops on a virtual hilly section of a high-speed railway, as well as regression equations for determining their of numerical values, which are recommended for implementation in the practice of the locomotive complex of the Uzbek railways.

1 Introduction

Recently, there has been a significant increase in the volume of railway transportation of goods by locomotives of electric and diesel traction on sections of the Uzbek railways. Moreover, to a greater extent, the specified volume of freight traffic is implemented by the main diesel locomotive fleet of JSC "O'zbekiston temir yo'llari", which is based on high-performance Uzbek diesel locomotives *UzTE16M* in various sectional designs. Therefore, the foregoing predetermines the conduct of research, the results of which will be aimed at improving the efficiency of the transportation work of locomotives diesel traction in real conditions of traffic organization on sections of Uzbek railways of various difficulty.

2 Objects and methods of research

Modern transport systems are complex technical objects consisting of elements and are classified according to various technological features. Depending on the power plant, they are divided into aerospace vehicles, cars, diesel and electric traction locomotives, gas turbo locomotives, and others.

We present an overview of scientific research devoted to studying the effectiveness of various transport systems (complexes) and their elements in operating conditions.

The development of a new technology for smelting and out-of-furnace processing of structural alloyed steel 20GL in a steel-pouring ladle, taking into account the processes of deep deoxidation, refining of melts from harmful impurities and modification, the use of

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rare earth metals and solid slag mixtures, is the subject of recent studies by Russian and Uzbek scientists [1-3].

High-manganese steel 20GL is widely used to manufacture parts and metal structures intended for railway transport, particularly basic cast elements for automatic coupling devices of locomotives and passenger and freight railway cars.

The authors of these studies [1-3] proposed compositions of deoxidizing-refining-modifying complexes that can simultaneously purify the melt from harmful impurities and, in parallel, affect the properties of steel through a change in the size and shape of the components of the metal crystal lattice. The foregoing made it possible to increase the wear resistance of steel 20GL, reduce the amount of oxide, sulfide, and non-metallic inclusions, and reduce the size of carbides, which was shown in the work of the authors [4]. Here, the authors also offer recommendations on the manufacturing technology and organization of the production of cast billets for railway rolling stock.

The authors' works [5, 6] present the results of studying the influence of general and component parameters on the characteristics of turbojet engines, taking into account the performance of the operating cycle under various optimal operating modes and an empirical assessment of the thermodynamic cycles of turbojet engines to obtain quantitative indicators and characteristics of the fuel injection and combustion processes for stationary engine research.

The authors [7, 8] investigate the issues of increasing the fatigue life and operational reliability of the blades and disk of a high-pressure turbine of turbojet engines by improving the surface protection and cooling them, taking into account the effect of load changes and average stress on them.

Articles [9-12] provide surface analysis, residual stress values, fractography, as well as the results of metallographic studies and axial fatigue tests of an electrically conductive material made from nickel-based Inconel® 718 alloy, taking into account the assessment of its surface roughness for various parameters of electrical discharge machining using copper, brass and copper-tungsten electrodes.

The authors of studies [13, 14] propose to ensure the high operational reliability of units, systems, and assemblies of locomotives under operating conditions by introducing modern developments in the electrical industry and computer technologies into practice.

Works [15, 16] are devoted to the study of ways to reduce the consumption of fuel and energy resources for train traction, in which it is proposed to save natural diesel fuel by diesel locomotives and electric energy by electric locomotives by optimizing the operating modes of power energy systems (installations) of diesel and electric locomotives.

The authors of [17-19] recommend improving (increasing) the qualitative component of the current collection process by optimizing the current collection modes by normalizing the upper and lower limits of contact pressure and by using mechanical and electrical means of protection against the occurrence any of resonant of the oscillations in the traction network.

The study [20] shows that by modeling a simplified traction power supply system, based on the analysis and simulation of the process of passing the neutral inserts of the contact network by an electric locomotive, it is possible to avoid the magnitude of the overvoltage at which it will be possible to increase the voltage during the phase separation process, which will significantly reduce the threat to the safety operation of the electric train on the route way.

The authors of the study [21] recommend a model and an optimization algorithm for choosing the train route for daily planning of freight rail transportation by redistributing the car traffic, taking into account the time of delivery and departure of goods between successive trains, which will reduce the total travel time on the route way of a freight train and ensure timely delivery cargo.

An analysis of the research results [1-4] and the presented works [5-21] indicates the degree of study of the problem of substantiating the efficiency of using various transport systems by increasing operational reliability by increasing the wear resistance of structural alloyed steels, of further improving repair production and providing the possibility of reducing fuel consumption and energy resources for train traction.

However, in these studies, the issues of the stopping process along the route of the rolling stock on sections of varying complexity of railways were not considered. In this regard, the issues of substantiating the logistic kinematic parameters of the movement of a freight train and their components at stops at intermediate and terminal stations of various sections of the railway, including high-speed ones, remain insufficiently studied.

Therefore, the purpose of this study is to clarify the logistic kinematic parameters by the path of movement, speed, and time along the route of freight trains, taking into account the time for accelerations - deceleration (components of the logistics of movement) in the process of organizing their stops at intermediate and final stations of a virtual hilly section of the railway, where organizational and technological operating conditions are taken close to real.

These studies were carried out in parallel with the works [22, 23], and therefore the basis of the developed algorithm for the implementation of the formulated research goal was the methods and ways [23, 24] of the theory of locomotive traction, the initial data on the material and technological conditions for organizing the transportation work of freight locomotives on a straightened profile track of the investigated section of the railway, object, and subject of research [25].

The object of study was freight trains with different weights and the same number of train axles, three-section mainline (train) freight diesel locomotives of the *UzTE16M3* series, and a straightened track profile of the second type of a virtual hilly section of the railway.

The subject of the study is the kinematic parameters of the movement of a freight train, taking into account the analysis of the features of its stopping process at the intermediate and final stations of the section of the railway for different masses and a constant number of axles of the train.

Design features, technical parameters, traction characteristics, energy, and operational performance of the investigated freight diesel locomotive *UzTE16M3* [26], as well as the characteristic of the straightened path profile of the virtual hilly section of the high-speed railway, are covered in detail in [27].

3 Results and their discussion

Table 1 shows the numerical values of the kinematic parameters of the movement of freight trains for each stage of a virtual hilly section of the railway in different modes of operation of the power plants of diesel locomotives *UzTE16M3* without stops and with stops at an intermediate station in the implementation of rail transportation of goods, taking into account the time for deceleration - acceleration.

Analysis of the average values of the kinematic parameters of Table 1 shows that the movement of the studied freight trains on a virtual hilly section of the railway, organized without stops at an intermediate station, provides an increase in the technical speed of movement by 11.9 km/h and a decrease in the share of movement in mode traction by 6.05 percent.

Table 1. Time distribution of a freight train on the hauls of the hilly section *D - F*, diesel locomotives *UzTE16M3*

No. in order	Mass of composition Q , t	Speed movements V , km/h	Without stops / With stops, min		
			on the haul	in mode	
				of traction	of idle and braking
<i>Haul D – E</i>					
1	3500	68.92/64.00	19.50/21.00	18.20/16.80	1.30/4.20
2	3000	74.25/68.57	18.10/19.60	16.10/15.00	2.00/4.60
3	2500	77.68/71.11	17.30/18.90	15.40/14.80	1.90/4.10
<i>Haul E – F</i>					
1	3500	9276/72.86	15.20/19.35	7.10/10.15	8.10/9.20
2	3000	96.57/74.80	14.60/18.95	8.00/10.90	6.60/8.05
3	2500	95.91/77.47	14.70/18.20	6.80/8.90	9.80/13.40
<i>Section D – F</i>					
1	3500	79.36/68.25	34.70/40.35	25.30/26.95	9.40/13.40
2	3000	84.22/71.44	32.70/38.55	24.10/25.90	8.60/12.65
3	2500	86.06/74.23	32.00/37.10	22.20/23.70	9.80/13.40
Averages values		83.21/71.31	33.13/38.67	23.87/25.52	9.26/13.15

Comparative analysis of the data in Table 1, taking into account studies [26], shows that for average values of kinematic parameters, the movement of freight trains with different masses and a constant number of axles of the train on a virtual hilly section of the railway track, organized with stops at an intermediate station concerning a similar movement without stops at it, contributes to:

- an increase in the total travel time of the train by 5.54 minutes and a decrease in the technical speed of movement by 11.9 km/h, with an average estimated time per stop of approximately 2.77 minutes;

- the values of the shares of movement in modes traction at 65.99 percent and idling and braking at 34.01 percent;

- a decrease in the share of driving in modes traction and an increase in the share of idling and braking driving by approximately 6.06 percent.

On Fig. 1 and Fig. 2, respectively, shows the numerical values and dynamics of the kinematic parameters of the stopping process - diagrams of the change in the distance that freight trains travel in the event of stops at the intermediate and final stations and the graphical dependences of their speeds at the start of braking and as a result of the completion of acceleration at these stations.

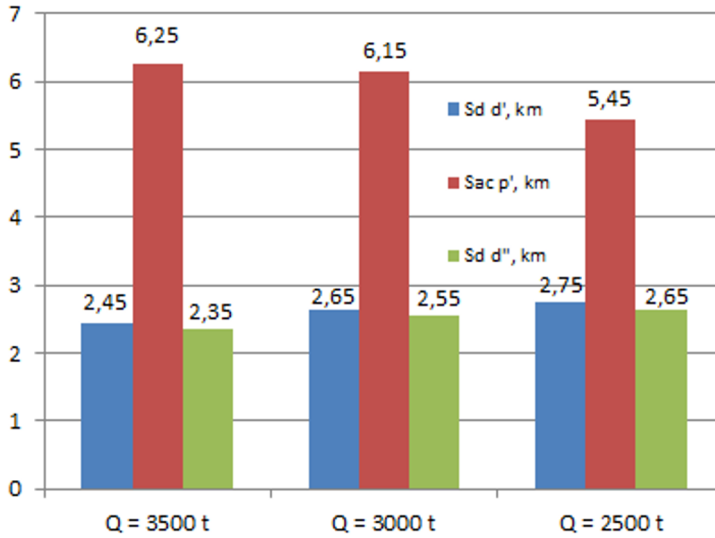


Fig. 1. The path traveled by a freight train when braking and starting off at the intermediate station and the arrival station

On fig. 1 and Fig. 2, similarly to [24, 28] is denoted: $S_{d d'}$ and $S_{d d''}$ are path for slowing down a freight train, respectively, at an intermediate station and an arrival station in the event of a freight train braking; $S_{ac p'}$ is acceleration path of a freight train at an intermediate station when starting off; $t_{d t'}$ and $t_{d t''}$ are deceleration time of a freight train, respectively, at an intermediate station and an arrival station in the event of a freight train braking; $t_{ac t'}$ is acceleration time of a freight train at an intermediate station when starting off; $V_{b br'}$ and $V_{b br''}$ is the speed of the freight train at the beginning of braking, respectively, at the intermediate station and the arrival station; $V_{ac sp'}$ is speed of movement of a freight train at the moment of "catch-up" of a non-stop train at an intermediate station.

Path of slow down $S_{d d'}$ and $S_{d d''}$ are the distance that a freight train travels from the start of braking (transferring the driver's crane handle to the braking position) to the complete stop of the train. Acceleration path $S_{ac p'}$ is the distance a freight train travels from the moment it starts moving off at an intermediate station to the moment it completes its acceleration.

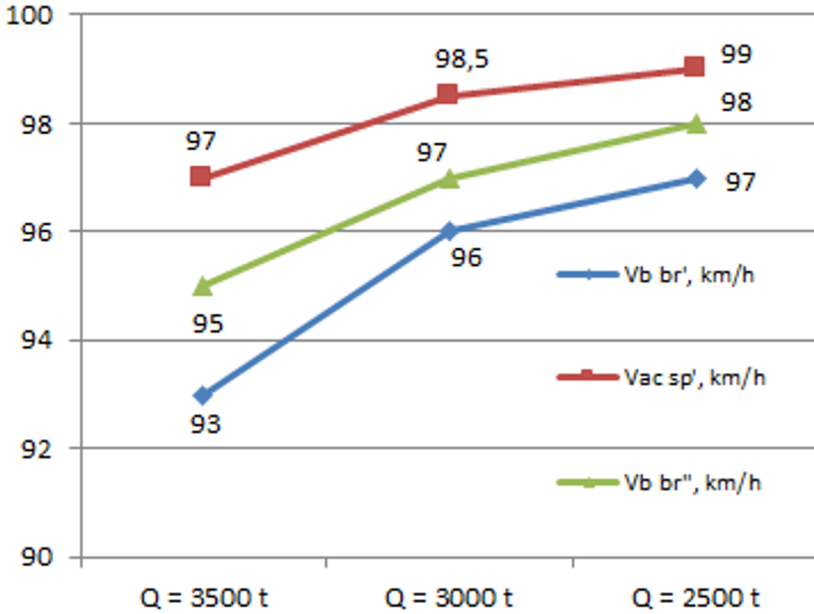


Fig. 2. The speed of the freight train at the beginning of braking and the end of acceleration at the intermediate station and the arrival station

According to the path change diagrams in Fig. 1 and graphic dependences of movement speed change in Fig. 2, it can be seen that with an increase in the mass of the freight train in the case of braking at the intermediate station and the arrival station, the deceleration distance decreases $S_{d\ d'}$, $S_{d\ d''}$ and an increase in the acceleration path $S_{ac\ p'}$. At the same time, the speeds of movement $V_{b\ br'}$ and $V_{ac\ sp'}$ accompanying them along station D and the speed of movement $V_{b\ br''}$ along station F decrease.

Moreover, the rate of change (increase or decrease) in the values of the above increases and decreases, depending on the change in the mass of the freight train, is also different.

The rates of change (increase or decrease) of the values of the kinematic parameters of the stopping process at the intermediate and final stations calculated by the authors for the path and speed of movement of freight trains with each successive increase - decrease in their mass of the train by a fixed value equal to $\Delta Q = 500$ t, are given in table 2.

In Table 2, the rate of change (increase or decrease) of values should be understood as a certain corresponding numerical value, which for each successive increase - decrease in the mass of a freight train, is determined as the ratio of the subsequent value of the parameter in question (path or speed) to the previous value. For example: when the mass of the train decreases from $Q_3 = 3000$ t to $Q_2 = 2500$ t of a freight train, the rate of change in the speed of movement $V_{ac\ sp'}$ at the end of acceleration at the intermediate station will be 1.0051 units, that is, $V_{ac\ sp2'} = 99$ km/h: $V_{ac\ sp3'} = 98,5$ km / h = 1.0155 units, and with an increase in the mass of the train from $Q_2 = 2500$ tons to $Q_3 = 3000$ tons of a freight train, the rate of change in the acceleration path $S_{ac\ p'}$ at the intermediate station will be 1.1284 units, that is $S_{ac\ p3'} = 6.15$ km: $S_{ac\ p2'} = 5.45$ km = 1.1284 units.

Table 2. Kinematic parameters of the stopping process of a freight train on a hilly section of the railway, diesel locomotives *UzTE16M3*

No. in order	Conditions transportation work		Kinematic parameters of the stopping process of a freight train					
	composition mass Q, t	number of axles m , axles	Path of deceleration and acceleration			Speed movement during braking and acceleration		
			by station $E, S_{d d}'$	by station $F, S_{d d}''$	by station $E, S_{ac p}'$	by station $E, V_{b br}'$	by station $F, V_{b br}''$	by station $E, V_{ac sp}'$
1	2	3	4	5	6	7	8	9
The rate of change of kinematic parameters when a freight train stops								
With an increase in the mass of the composition								
1	2500	200	-	-	-	-	-	-
2	3000	200	0.9636	0.9623	1.1284	0.9897	0.9898	0.9949
3	3500	200	0.9245	0.9216	1.0163	0.9687	0.9794	0.9848
4	Averages values		0.9440	0.9419	1.0723	0.9792	0.9846	0.9898
With a decrease in the mass of composition								
1	3500	200	-	-	-	-	-	-
2	3000	200	1.0816	1.0851	0.984	1.0322	1.0210	1.0155
3	2500	200	1.0377	1.0392	0.886	1.0104	1.0103	1.0051
4	Averages values		1.0596	1.0621	0.935	1.0213	1.0156	1.0103

The dynamics of changes in the kinematic parameters logistics of the stopping process by the way, the speed of movement, and the travel time in the along route way of a freight train in the range of the variation (differentiation) interval accepted by the authors by the value $\Delta Q = 500$ tons of train mass (from $Q_3 = 3500$ tons to $Q_1 = 2500$ tons) are described by the following analytical dependencies:

Path for slowing down a freight train at an intermediate station

$$S_{d d}' = -0.05Q^2 + 0.35Q + 2.15 \quad R^2=1.0 \quad (1)$$

Path for slowing down a freight train at an arrival station

$$S_{d d}'' = -0.05Q^2 + 0.35Q + 2.05 \quad R^2=1.0 \quad (2)$$

Acceleration path of a freight train at an intermediate station when starting off

$$S_{ac p}' = -0.3Q^2 + 0.8Q + 5.75 \quad R^2=1.0 \quad (3)$$

The speed of the freight train at the beginning of braking at an intermediate station

$$V_{b br}' = -1.0Q^2 + 6Q + 88 \quad R^2=1.0 \quad (4)$$

The speed of the freight train at the beginning of braking at an arrival intermediate station

$$V_{b br}'' = -0.5Q^2 + 3/5Q + 92 \quad R^2=1.0 \quad (5)$$

The speed movement of a freight train at the moment of acceleration at an intermediate station

$$V_{ac\ sp}' = -0.5Q^2 + 3Q + 94.5 \quad R^2=1.0 \quad (6)$$

The time of the freight train at the beginning of braking at an intermediate station

$$t_{d\ t}' = 0.015Q^2 - 0.035Q + 1.47 \quad R^2=1.0 \quad (7)$$

The time of the freight train at the beginning of braking at an arrival station

$$t_{d\ t}'' = 0.005Q^2 + 0.005Q + 1.64 \quad R^2=1.0 \quad (8)$$

The time movement of a freight train at the moment of acceleration at an intermediate station

$$t_{ac\ t}' = -0.05Q^2 - 0.25Q + 3.1 \quad R^2=1.0 \quad (9)$$

In formulas (1) - (9), a sufficient value of the approximation reliability $R^2 = 1.0$ is given (the necessary reliability condition is $R^2 \geq 0.8$), and the value $Q_t = 1.2.3$ indicates the option traction calculation.

The analysis of the above regression equations shows that the dynamics of the mentioned logistic parameters, depending on the change in the composition mass of the freight train, is described by a polynomial of the second degree with 100% calculation accuracy and is in good agreement with the research data [23, 25, 26], which were carried out for three-section mainline (train) freight diesel locomotives of the series UzTE16M3 on a real section of the Uzbek railway.

4 Conclusion

Based on the research carried out, the authors obtained the following results:

1. Logistic kinematic parameters of the movement of freight trains of various composition masses, implemented by the investigated diesel locomotives of the UzTE16M3 series in the process of rail transportation of various types, views, structures, and content of goods on a virtual hilly section of the railway track are substantiated.

2. Graphical dependences (histograms) and fluctuation rates of the main logistic kinematic parameters and their components during freight train movement in the accepted range of train mass changes during stops at intermediate and final stations of a virtual hilly section of the railway are obtained.

3. Regression equations have been compiled to determine the mainline components of the logistics parameters of the movement of a freight train - along the length of the path, of the values of the speed and time of movement in the route of a freight train with different masses of compositions train at stops on a virtual hilly section of the railway.

The logistic kinematic parameters of the movement of freight trains and the transportation work of three-section mainline (train) freight diesel locomotives of the UzTE16M3 series obtained by the authors, their components are recommended for practical use in Uzbek locomotive depots, which can be implemented on hilly sections of railways with the second type of track profile, including of high high-speed, in real operating conditions.

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