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Methodology for Assessing the Efficiency of Using Diesel Locomotives on Railways Sections

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Abstract

A methodology is presented for substantiating the operational efficiency of the transportation work of locomotives, based on the data of route sheets and speed measurement tapes of the locomotive driver. Analytical expressions are proposed for the developed algorithm for the numerical study of mechanical work and diesel fuel consumption of diesel locomotives, and the calculation of their components (commands) using a computer hardware and software complex for a separate trip according to the route sheets of driver of the diesel locomotive. The results of processing speed measurement tapes and route sheets of diesel locomotive drivers on some real sections of the Uzbek railway are obtained in the form of tabular data, the analysis of which indicates that the most accurate and complete indicator characterizing the current energy state of locomotives of diesel traction will be the efficiency of the power circuit η of diesel locomotives.

Key Words: *Diesel locomotive, transportation work, efficiency, mechanical work, working stroke, idling, braking, fuel consumption, movement resistance, indicator.*

1 Introduction

Increasing the efficiency of transportation works of locomotives includes the task of reducing operating costs, a significant part of which is the cost of energy spent on traction of trains. Energy costs will be determined primarily by the realized efficiency of locomotives over the periods of their operation. This explains the great interest in studying the dependence of the efficiency of locomotives on operating conditions and finding ways to increase them.

The main production process of railways is the process of transportation work of locomotives (TWL), when certain characteristics and indicators can be divided depending on the period of their operation into object and operational characteristics (indicators).

In the first case, their values do not depend on operating conditions, but are determined only by the design of the object (locomotive, cars, etc.), and in the second, they are determined over a certain period of operation. These characteristics, being average for the period under consideration, will depend not only on the object characteristics, but also on the operating conditions on a specific section of the railway.

Depending on the accepted source data, object and operational characteristics or indicators are divided into design, when passport (design) data were used in their calculations, and real (actual), when actual source data taken from reports, measurements, experimental trips, and so on were used.

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Passport object characteristics of locomotives and cars are widely used in traction calculations and other types of numerical calculations.

The actual object characteristics of locomotives and cars can be found for individual units or their groups by conducting special experimental studies or experiences, as well as from reporting documents.

2 Objects and Methods of Research

Currently, scientists from far [1-7] and near [8-13] foreign countries attach great importance to research in the field of increasing the efficiency of using locomotives on railway sections by improving the organization and quality of repair production, by optimizing the transportation work of locomotives along the route rolling stock and through the introduction of original design and technological developments into the practice of working the locomotive complex of railways.

However, in their studies they all do not take into account the influence of operational factors on the organization of transportation work of locomotives, which and predetermines the continuation of research in this direction.

In this regard, the purpose of this study is to develop (improve) a methodology for identifying operational coefficient efficiencies transportation work of diesel locomotives on railway sections, which will allow us to evaluate the actually achieved efficiency of using a diesel locomotives behind individual trip, for a number of trips for a particular series of diesel locomotives, as well as for the depot as a whole.

As a result of the implementation of this research goal, it will be possible to clarify the fuel consumption standards planned for the depot, develop measures to reduce fuel consumption and assess the level of thermal technical condition of specific diesel locomotives, which is an element of in-place diagnostics. Since, when calculating the efficiency, the mechanical work of the forces acting on the train will be determined, this will also make it possible to clarify the between-repair runs of diesel locomotives and the cost of money for their technical maintenance and repair.

The operational period of the transportation work of locomotives includes periods of working running, idling and braking, which in total amount to the period of train travel, as well as periods of parking at stations and at signals.

In table 1 shows some types of operational efficiency of transportation work of locomotives. To calculate the given efficiency coefficients of locomotives, it is necessary to know their mechanical operation and fuel consumption, the values of which, using passport source data, form the basis for traction and energy calculations.

In the given expressions in table 1 indicate:

A_t – tangential mechanical work of the locomotive during the trip, kgf km;

$\sum A_7$ – tangential mechanical work for all trips of the period under review, kgf кkm;

K_e – energy equivalent of mechanical work, kg/kgf km;

$\sum E$ – total fuel consumption for the operating period under consideration (revolution, day, month, etc.), kg;

$\sum A^{"}$ – total mechanical work of the forces of total resistance to the movement of composition for the period under consideration, kgf km;

$A^{"}$ - mechanical work of the forces of total resistance to the movement of the composition behind a trip, kgf km;

E_{tr} – total fuel consumption for the trip, kg;

E_{run} fuel consumption during the period of movement (running) of the train during the trip, kg;

$E_{w\,st}$ - fuel consumption during in the travel trip working stroke period, kg;

E_t – fuel spent on creating the tangential mechanical work of the locomotive, kg;

E_{ser} – fuel consumption for auxiliary (service) needs behind the period of train running (movement), kg.

Table. 1: Operational Coefficientы Efficiencies of Transportations Work of Locomotives and Formulas for their Calculation.

Number in order	Types of operational coefficients efficiency behind period of transportation work of locomotives	Calculated formulas
1 2 3	2	3 5
	for turnover, day, month	
1	gross	$\eta^{e}_{gr} = \frac{K_e \sum A_t}{\sum E}$ (1)
	net	$\eta^{e}_{net} = \frac{K_e \sum A^{"}}{\sum E}$ (2)
	per trip	
2	gross	$\eta_{gr} = \frac{K_э A_t}{E_{tr}}$ (3)
	net	$\eta_{net} = \frac{K_e A^{"}}{E_{tr}}$ (4)
	movement in travel trip	
3	gross	$\eta^{gr}_{run} = \frac{K_e A_t}{E_t}$ (5)
	net	$\eta^{net}_{run} = \frac{K_e A^{"}}{E_t}$ (6)
	efficiency coefficient of work stroke	
4	per trip	$\eta_{w\,st} = \frac{K_e A_t}{E_{w\,st}}$ (7)
	efficiency coefficient of power circuit	
5	per trip or work stroke period	$\eta = \frac{K_e A_t}{E_{tr} - E_{w\,st}} = \frac{K_e A_t}{E_t}$ (8)

Source: Compiled by the Author».

Identification of the actual values of mechanical work and fuel consumption when determining the actual operational values of locomotive efficiency can be done based on the results of special experimental trips, which requires significant time and money, as well as on the basis of processing available reporting documents (speed measurement tapes, driver route sheets locomotive, TXOI reporting and others).

The latter path is of some interest, although in this case it is necessary to partially use object passport data (dependence of the main resistance to movement on speed and others). However, the data obtained quite fully reflect the actual results of the transportation work of locomotives and are of significant practical interest.

Identification of the actual values of mechanical work and fuel consumption during the travel period according to speed measurement tapes and route sheets of the diesel locomotive driver, as well as RTC data [14] includes the following calculations.

Using the speed measurement tape we have the mass (weight) of the train Q (t), the number of axles m, the series of the diesel locomotive (locomotive) and its mass (weight) P (t), travel time along the section t (h), graphical dependencies V(S), t(S), braking from the path and others.

The mechanical work of braking forces (N km, kgf km) for a specific trip is determined by the following formula:

$$\mathrm{A_{br}} = (\mathrm{P}+\mathrm{Q}) \cdot [0{,}394 \cdot 10^{-3}(1+\gamma)] \cdot$$

$$\sum_1^{\mu_{br}}\left(\mathrm{V}_{end}^2 - \mathrm{V}_{st}^2\right) - \sum_1^{\mu_k}(\mathrm{w}_{0\,idl} + \mathrm{i_k}) \cdot \Delta \mathrm{S_{br}} \qquad (9)$$

where γ – coefficient taking into account the influence of rotating masses on train acceleration. For full-load trains (at freight trains), you can take γ = 0.035; empty γ = 0.091, combined γ = 0.058, passenger – 0.052;

V_{st}, V_{end} – train speed movement at the beginning and end of braking, determined by speed measurement tapes, km/h;

μ_{br} – number of braking times per trip;

$w_{0\,idl}$ – the value of the specific main resistance to the movement of the train with the traction machine turned off at an average speed of movement at a selected interval of the braking distance, N/kN (kgf/t);

ΔS_{br} – braking way distance interval, km. Selected in braking sections at braking speed intervals of no more than 10 km/h within $V_{st} - V_{end}$;

μ_k – number of intervals ΔS_{br}, where the calculations were made values $w_{0\,idl}$;

i_k – straightened climb (slope) on which braking was performed.

The value $w_{0\,idl}$ is calculated by the formula:

$$w_{0\,idl} = \frac{P \cdot w_l + Q \cdot w_0^{"}}{P+Q} \qquad (10)$$

where w_l, $w_0^{"}$ – specific main resistance to movement of the locomotive and composition at idle speed. These values will be calculated according to RTC standards [14].

The mechanical work of resistance forces to train movement (N km, kgf km) on the section under consideration will be

$$A = A' + A^{"} = P \cdot \left[\sum_1^{k_v}(w_0' + i_k)\Delta S_v + \sum_1^{k_x}(w_l + i_k)\,\Delta S_l\right] +$$

$$Q\sum_1^{k}(w_0^{"} + i_k)\Delta S \qquad (11)$$

where A', A'' - mechanical work of the total resistance forces to the movement of the locomotive and composition;

k_v, k_x – the number of intervals for calculating the values of w_0' and w_l in the corresponding sections of the route with the traction machine turned on and idling, as well as braking;

k - the total number of speed intervals not exceeding 10 km/h, selected to calculate specific the main resistance to movement on the site;

w_0', w_l, w_0'' - specific basic resistance to movement of a locomotive as a cart, at idle and train at average speed in the accepted interval speed movement, N/kN (kgf/t). Determined according to RTC standards [14, 15] for travel trip conditions;

ΔS, ΔS_v, ΔS_l - corresponding path intervals, km. Selected according to appropriate speed intervals no more than 10 km/h.

For the train to move from the moment it starts to stop on the section under consideration, the mechanical tangential work of the locomotive will be

$$A_t = A + A_{br} \tag{12}$$

The total fuel consumption E_{tr} for the trip is determined by measurement and recorded in the locomotive driver's route sheet. Fuel consumption (kg) during the period of movement (stroke) of the train will be

$$E_t = E_{tr} - E_{add} \tag{13}$$

where E_{add} - additional fuel consumption during stops at intermediate stations and at signals (E_{sig}) and consumption at locomotive crew turnover stations (E_o).

Usually

$$E_{add} = E_{sig} + E_o \text{ или } E_{add} = g_{idl} \cdot (t_{st} + t_o) \tag{14}$$

where t_{st} - total time spent (stops) at intermediate stations and at signals, min;

t_o - downtime at locomotive crew turnover stations, min;

g_{idl} - fuel consumption for service needs, kg/min. It is taking according to RTC data [14] and clarified by experimental trips.

Fuel consumption to create mechanical tangential work of the locomotive per trip will be:

$$E_t = E_{run} - E_{ser} \tag{15}$$

where E_{ser} - fuel consumption for auxiliary (service) needs during the travel time period, kg;

Fuel consumption for auxiliary needs is determined by the formula:

$$E_{ser} = g_{idl} \cdot t \tag{16}$$

where t - train travel time (movement) per trip, min.

If using a speed measurement taping it is possible to determine the total time of movement with the traction machine turned off and braking periods, then it will be possible to determine fuel consumption during the working stroke period, namely:

$$E_{w\,st} = E_t - g_{idl} \cdot t_{\text{хт}} \tag{17}$$

where $t_{idl,\,br}$ - time of running (moving) of a train at idle and braking, min.

3 Results and their Discussion

In table 2 shows the results of processing speed measurement tapes and route sheets of a diesel locomotive driver on one of the sections of the Uzbek railway, from which it can be seen that there is a significant difference between the efficiency values gross η_{br} and net η_{net}, which indicates high energy consumption for braking (the value of A_{br} is approximately 22.9 percent of the value A_t). Efficiency value power circuit η = 0.311 is quite high, which indicates that the driver uses rational positions of the driver's controller during the working stroke, but this benefit is offset by braking.

Table 2: Efficiency Coefficient Calculation Results Transportation Work of Locomotives on the X-L Section (Even Direction), Diesel Locomotive 2TE10L, Q = 3314 T, M = 204 Axles, L = 85,6 Km, $I_{кс}$ = 0,645 ‰ (On Deciphering of the Speed Measurement Tape).

Mechanical work *A*, kgf km	A'	A''	A_{br}	A	A_t	
	90000	716000	239000	806000	1045000	
Diesel fuel consumption E, kg	E_{tr}	E_{run}	$E_{w\,st}$	E_t	-	
	891	847	828	788	-	
Coefficient efficiency η_i transportation work of locomotive	η_{br}	η_{net}	η_t^{br}	η_t^{net}	$\eta_{w\,st}$	η
	0,277	0,190	0,289	0,198	0,245	0,311

Source: Compiled by the Author».

Analysis of the interconnectedness of the value A_t with its components, expressed through the forces of primary, additional and artificial resistance (braking), made it possible to propose the following expressions:

for freight trains

$$A_t = A_Q + A_m + \Delta A_t + A_z = A + A_{br} \quad (18)$$

for passenger trains

$$A_t = A_Q^{pas} + \Delta A_t^{pas} + A_z \quad (19)$$

where A_Q - mechanical work of the total forces of the locomotive and the composition, as well as braking forces, depending only on the weight of the train and the series of the locomotive on the site for a given variant work of the trip at an estimated in travel time t_{cal} and at the average number of stops z_{cal}, ($A_Q = A' + A''_Q$) kgf km;

A_m - mechanical work of the basic resistance and braking forces, depending only on the number of axles in the train at t_{cal} and z_{cal}, kgf km;

ΔA_t, ΔA_t^{pas} – change in the mechanical operation of the locomotive, taking into account the deviation of the actual travel time on a given trip from its accepted calculated value with an average weight of the train Q_{cal}, an average number of axles m_{cal} and stops z_{cal}, kgf km;

A_z – mechanical work of the locomotive on the section due to the deviation of the actual number of stops (z) from their accepted calculated value (z_{cal}) and the magnitude of the mechanical work of the main resistance forces per stop depending on the mass (weight) of the train at m_{cal} and t_{cal} ,kgf km;

A_Q^{pas} – component of mechanical work, including explanations for quantities A_Q and A_m, kgf km.

Detailed expressions of the indicated terms for freight and passenger trains are given in the author's monograph [16].

To calculate the efficiency, it is necessary to have the value of the mechanical work of the forces of total resistance to the movement of the composition, that is

$$A^{"} = L\left[Q\left(\alpha_Q \cdot c + i_{\text{кс}}\right) + \alpha_m c_V^{cal} \cdot m\right] \quad (20)$$

In the given expressions it is indicated:

L - length of the section of the considered work option, km;

P - mass (weight) of the locomotive, t;

w' - averaged specific basic resistance of the locomotive, N/kN (kgf/t). Due to the insignificant influence of the value of w' on the value of A_t and the impossibility of identifying the distribution of periods of working and idling during a trip according to the route sheets of the locomotive driver, we take approximately $w' = 0{,}5(w_0' + w_{idl})$, that is, the sum of half the main resistance locomotive w_0' and at idle w_{idl};

$i_{\text{кс}}$ - path-weighted average value of the reduced rise on the section, ‰;

Q, m – weight (mass) of the train (t) and number of axles in the train (axles);

c – free term of the formula for specific the main resistance to movement of a composition of railway cars, N/kN (kgf/t);

A_t^{cal} – tangential mechanical work of the locomotive under design conditions, that is, Q_{cal}, m_{cal}, t_{cal}, z_{cal} for the considered work option, N km (kgf km);

β - indicator of mechanical work costs for braking, determined by design conditions;

c_V^{cal} - axial characteristic specific of the main resistance of the composition at the estimated running time, N/axles (kgf/axles). Magnitude $c_V^{cal} = c_0^v + c_1^v \cdot V_{cal} + c_2^v \cdot V_{cal}^2$, a c_0^v, c_1^v, c_2^v - coefficients of the formulas for the main resistance of railway cars, which are taken according to RTC data [14, 15];

V_{cal} – average speed by estimated time, km/h;

$\alpha_t^{ac}, w_{ac}', c_V^{ac}$ - corresponding values for the actual travel time of a given trip (according to the locomotive driver's route sheet);

$\alpha_t^{cal}, w_{cal}', c_V^{cal}$ – the same for the estimated travel time;

$\delta Q = a_{\alpha_z} + b_{\alpha_z} \cdot z$ – the dependence of the additional mechanical work of the forces of total resistance to movement per one stop of the train on the weight (mass) of the train, when m_{cal} and t_{cal}, N km/stop (kgf km/stop).

Expressions (1) - (8) and (12) - (20) can be used as the basis for an algorithm for calculating mechanical work per trip on a computer, according to which tables are compiled to determine the terms of mechanical work (table 3) of locomotives according to the driver's route sheets of diesel locomotive

Calculations of the components of the tangential mechanical work of a locomotive during a trip using such tables are carried out according to expressions (11.18) and (11.22) - (11.25) given in the author's monograph [16]. Actual fuel consumption is determined based on the diesel locomotive driver's route sheets, using expressions (12) - (17).

Table 3: Data On the Components of Tangential Mechanical Work of Diesel Locomotives 2TE10L for Locomotive Depot T.

δQ, kgf km/stop	**Composition mass Q, t**	**Work option sections**		
		T - A	T - K	T - D
		A - T	K - T	D - T
1	2	3	4	5
		Magnitude A_Q, kgf km		
3800	600 - 700	74700	125100	93200
		66750	63500	84100
5100	701 - 800	76200	130200	95300
		67100	64500	85250
= = = = = = = = = = = = = = = == = = = = = = == = = = = = = == = = = = = = = = = =				
25100	3301 - 3400	427050	895200	734000
		405100	534300	702900
25700	3401 - 3500	445300	917100	740200
		415200	582700	707100
		Magnitude A_m, kgf km		
Number of axes	22 - 28	91300	76400	52400
		93130	77350	50250
	30 - 36	92600	77800	53100
		94800	76450	51700
= = = = = =	= =	= = = = = =	= =	= =
= = = = = =	= =	= = = = = =	= =	= =
= = = = = =	= =	= = = = = =	= =	= =
Number of axes	222 - 228	520100	424400	372100
		540300	440200	351200
	230 - 236	526700	438000	384400
		547400	456200	360000
		Magnitude A_t, kgf km		
Actual movement time, h	2,11 – 2, 20	17400	27800	12720
		15700	0	11350
	2,21 – 2,30	0	18900	6670
		0	-4750	0
	= =			
	3,11 – 3,20	-34800	-14200	-7370
		-33100	-15300	-8170

Source: Compiled by the Author».

Having all the data, calculations of the operational coefficient efficiency of the transportation work of locomotives are carried out according to formulas (1) - (8). To determine the operational efficiency of the transportation work of locomotives per day, month, the necessary data is selected for a given period of time and calculations are performed using formulas (1) and (2).

In table 4 shows the results of determining the operational coefficient efficiency of a trip on one of the sections of the Uzbek railway for the diesel locomotive 2TE10L, where the numerator shows data towards the depot station, and the denominator shows data from the depot station.

Table 4: Efficiency Coefficient Calculation Results Transportation Work of Locomotives on Section X - D (Even Direction), Diesel Locomotive 2TE10L, Q = 3230 T, M = 220 Axles, L = 89,4 Km, $I_{кс}$ = 0,35 ‰.

Mechanical work A, kgf km - according to (18), (20) and (11.21) - (11.27) [15]	A_Q	A_m	ΔA_t	A_z	$A^{''}$	A_t
	348800	46000	38000	74000	794000	920800
Diesel fuel consumption E, kg – according to (13) – (17)	E_{tr}	E_{run}	$E_{w\ st}$	E_{ser}	E_t	-
	828	790	732	776	714	-
Coefficient efficiency η_i transportation work of locomotive - according to (3) – (8)	η_{br}	η_{net}	η_t^{br}	η_t^{net}	$\eta_{w\ st}$	η
	0,261	0,225	0,273	0,236	0,295	0,303

Source: Compiled by the Author».

In this table, calculations of mechanical work are made on the basis of modeling the travel process according to formulas (18) - (21), and diesel fuel costs are taken according to the diesel locomotive driver's route sheets with clarification of the consumption terms according to expressions (15) - (17).

The efficiency of the power circuit (η) for the trip and the working stroke period will be the same, and for different travel conditions on certain sections of the railway for a given series of diesel locomotive it will vary depending on the selected positions of the working stroke driver's controller within rather narrow limits.

4. Conclusion

As a result of the study, the following general conclusions and recommendations were obtained.

1. A methodology for determining the operational coefficient efficiency of the transportation work of diesel locomotives (locomotives) has been proposed and justified, the use of which makes it possible to identify the mentioned efficiency factors from route sheets and speed measurement tapes of locomotive drivers.
2. For the studied diesel locomotives 2TE10L and TEP10 [16], the value of the efficiency of their power circuit under the specified operating conditions will be in the range η = 0.28 - 0.31. Other efficiency coefficients of locomotives transportation work will vary within very wide limits, excluding the efficiency coefficient of the working stroke $\eta_{w.st}$ per trip, the value of which will vary within slightly larger limits than the efficiency value. η of power circuit.

3. The largest fluctuations can occur for coefficient efficiency values - gross and efficiency - net operating period (turnover, day, month, etc.), since, during the period under review, significant unproductive costs associated with downtime, repairs, and others.
4. It has been proven that the efficiency of the power circuit η of diesel locomotives will be the most accurate and complete indicator of the energy state of diesel locomotives, and numerical calculations can cover all trips according to work options, and then determine the overall operational efficiency of locomotives of the entire depot.

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